Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Roadway Deployment Analysis

U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-RD-95-031
November 1994

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
Research
and Development

NOTICE

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report investigates issues and risks related to roadway infrastructure deployability of automated highway systems in both urban and rural settings in the context of case studies of existing freeway corridors in California. The overall conceptual structure of the research is that of a Baseline Study followed by Case studies.

The Baseline Study consisted of an analysis of candidate urban and rural area freeway corridors in California from which the specific case study corridors were chosen. Initially, 52 candidate urban freeway corridors were identified from the most heavily congested urban areas in California, in the San Francisco Bay Area and the greater metropolitan regions of Los Angeles, San Diego, and Sacramento. In the rural area, initially, 14 freeway corridors were identified that linked urban centers, including Los Angeles, San Francisco, San Diego, Sacramento, Bakersfield, and Fresno.

Criteria were then selected to be used in the classification analysis of the candidate corridors as well as in the case studies selection process. For the urban analysis, such criteria consisting of the physical features that represented potential constraints to the accommodation of an automated highway facility were of prime importance since the project's focus was roadway infrastructure deployment, including the following:

- vehicle overpasses
- pedestrian overpasses
- railroad overpasses
- soundwalls
- retaining walls
- frontage roads
- land use restrictions
- tunnels
- median width
- number of lanes
- type of terrain

Other corridor characteristics, such as congestion, safety, and air pollution, were also included in the case study corridor selection process to produce a more complete corridor profile. For the rural area corridors, the following characteristics were examined to classify the corridors by type:

- terrain
- median attributes
- land use restrictions
- overpass characteristics.

Twenty-four of the 52 corridors were eliminated from further examination due to a lack of diversity and representativeness of these physical features. Of the 14 rural area corridors initially identified, seven were removed from further consideration since they linked either out-of-state destinations for which data would be difficult to obtain, or did not link major urban areas. The seven remaining corridors link major urban centers in the State for which it was felt that automated travel would be more reasonable.

A detailed analysis was then performed on the remaining 28 urban freeway corridors relative to the primary roadway physical characteristics. The primary question asked was: What percentage of corridors have a certain characteristic over what portion of corridor length? The answers provided insight into the degree to which the physical features posed constraints to the roadway deployment of automated highway systems on these candidate corridors. Results of the distributional analysis of these 28 corridors indicated that only moderate constraints to the deployment of automated highway systems would be present from these physical features. The 28 urban freeway coorridors were then analyzed relative to congestion, accident rate, and extent of air pollution. After reviewing the final seven rural area corridors, three corridor categories were discerned based on qualitative differences among the four listed physical features.

Next in the urban corridor analysis was the development of a corridor ranking scheme. The objective in selecting the urban case study corridor was to choose, to the extent possible, the "worst" case corridor, that is, the corridor that presented the greatest challenge to automated highway systems roadway deployment. If viable automated highway systems deployment alternatives could be identified for this corridor, other corridors might be more responsive to the resolution of their own roadway deployment issues. In terms of the physical features, "worst" case corridor features referred to, for example, greater overpass densities, greater presence of restrictions to lateral expansion, more hilly and steep terrain, narrower median width, and fewer number of lanes.

Each attributes' data was first converted to a common ordinal scale to rank the corridors to allow comparison across different attribute measures. Several ranking schemes were evaluated to determine differences, if any, in the selection of the case study corridor. While there was small variation among the relative rankings among the corridors by ranking scheme, the selected urban corridor always retained its number one ranking. One such ranking scheme involved ranking the 28 urban corridors in order from 1 to 28, with one being highest, i.e. "worst" case, for each of the physical features, congestion, safety, and air quality measures. The physical features were first aggregated into a single "physical feature" ranking using equal weights among all the physical characteristics. At this stage in the selection process each corridor had ranking values for physical features, congestion, safety, and air pollution, each on a scale from one to twenty-eight. The final step was the assignment of weights for these four characteristics and the calculation of each corridor's total score. The physical features, congestion, safety, and air pollution rank values for each corridor were assigned the weights, 0.6, 0.2, 0.1, and 0.1, respectively. Because of the significance of the physical features, this rank value was substantively greater than the other three weights.

The number one ranked urban freeway corridor and choice for the case study was U.S. Route 101 in Los Angeles spanning 52.3 kilometers from the Los Angeles Central Business District through Hollywood to the western end of the suburban San Fernando Valley area of Los

Angeles. This urban case study corridor possessed overall the greatest degree of potential constraints to the accommodation of an automated highway system facility.

No ranking scheme was devised for the selection of the rural case studies. Instead, portions of the corridors from each of the three categories identified were selected for the subsequent rural corridor case studies. The corridors were a 16.1 kilometer portion of Interstate 5 located in the Central Valley, linking the Los Angeles area and the San Francisco Bay area, a 20.9 kilometer portion of Interstate 5 located in the Tehachapi mountains, between Los Angeles and the Central Valley, and a 31.0 kilometer portion of State Route 99 between Fresno and Sacramento in northern California.

For the urban case study corridor, automated highway system deployment concepts consisting of at-, above-, and below-grade configurations, were then evaluated given the corridor's physical roadway characteristics. Based on an examination of these concepts relative to evaluation criteria such as acquisition of right-of-way, cost, environmental impacts, and construction impacts, the deployment potential of each concept was determined relative to the corridor's physical characteristics.

Based on the above evaluation criteria, specific design criteria were formulated. The deployment of an automated facility through the conversion of existing traffic lanes, or the at-grade lane conversion concept, should be given priority over all other design options. The at-grade lane conversion concept is the least costly alternative to implement since right-of-way acquisition is either unnecessary or extremely minimal and the extent of modifications to the existing infrastructure is less extensive than the other alternatives, does not introduce any new seismic safety hazards, and does not result in any significant visual and noise impacts. Next, at-grade lateral expansion of roadways should utilize median areas to the extent possible. The use of available median space to accommodate lateral expansion is desirable since this land is already a part of the existing right-of-way, thereby minimizing the need for right-of-way acquisition. Third, the use of elevated structures should be avoided to the extent possible. Elevated structures are extremely costly to construct, require the use of costly exclusive entry/exit facilities, introduce new seismic safety hazards, and results in potential significant visual and noise impacts. Fourth, the use of tunnels should be avoided to the extent possible and should only be considered for relatively short distances. Like elevated structures, tunnels are extremely costly to construct and introduce new seismic safety hazards. In addition, tunnel construction may require the relocation of underground utilities. The length of tunnels would need to be limited and/or sufficient ventilation mechanisms would be required to avoid the accumulation of unsafe levels of vehicle emissions.

Based on the general uniformity of the primary physical characteristics of the urban case study corridor, the corridor was divided into 10 segments. For each segment, the feasibility of each of the design options was evaluated based on the physical characteristics of each segment. Due to the varying characteristics present throughout the length of the corridor, the recommended design concepts were not uniform throughout the corridor.

The lane conversion concept had the least difficulty for automated highway systems implementation for approximately 83 percent of the urban case study corridor's length. With this concept, lane barriers could be used to separate manual and automated vehicles with openings for entry and exit. Existing on- and off-ramps are utilized, minimizing construction costs and environmental impacts.

Splits and merges at freeway interchanges become more challenging with automated lanes. This situation occurs along Route 101 where it intersects two other freeways. Significant roadway modifications may be required to allow a continuous automated lane while providing all necessary options to both the automated and manual vehicles, since this interchange contains left lane splits and merges. A flyover construction was selected to provide continuous automated travel on the roadway through this complex multi-highway interchange, where there are left-lane splits and merges.

Where the portion of the corridor passes through the dense downtown area of Los Angeles, right-of-way availability is extremely limited. Adding additional lanes was not feasible, thus an above-grade structure was a possible option, where automated and manual vehicles are physically separated. Dedicated access and egress facilities, consisting of flyovers or ramps from existing overpasses, can provide separate entry and exit facilities for grade separated roadways. This concept would provide improved safety and operation through the physical separation of manual and automated vehicles. These exclusive entry and exit facilities, however, may require the acquisition of additional right-of-way and may impact traffic on local streets near such entry/exit facilities.

The emerging issues identified in the process of evaluating the automated highway system deployment concepts mostly pertained to operational features of the shared space concept (at-grade facility, requiring weaving through non-automated lanes), design considerations for the above- and below-grade automated facilities, environmental concerns associated with automated facilities relating to adjacent land use developments. Operational features of the shared space concept include the effects of weaving activities on the capacity of manual lanes where lane changes occur to access the automated lane through a transition lane, requirements of physical barriers and design solutions for separating automated, transition, and manual lanes, vehicle segregation within shared automated/manual facilities, and psychological impact of barriers on drivers. Design requirements for above-grade automated facilities include structural engineering of elevated structures, locations of exclusive entry and exit facilities for automated systems, and accommodation of manual lane splits and merges for automated facilities. Environmental concerns with automated facilities are generally associated with the design comparability with adjacent development, land use considerations, and traffic impacts on neighborhood arterials.

The implementation of automated highway systems within the three rural corridor segments were analyzed for two alternative deployment scenarios. Scenario 1 requires a minimum of four lanes in each direction, with automated and manual vehicles utilizing a common right-of-way. There would be one automated lane, a transition lane, and the remaining lanes would be manual lanes. Concrete barriers between the transition lane and automated lane, with openings for entry and exit, and between the transition lane and adjacent manual lane, with openings for movement between these lanes, would be required. To access the automated lane, vehicles would enter the freeway via existing on- and off-ramps and then enter the automated lane through the transition lane following successful check-in. To exit the automated lane, vehicles would enter the transition lane under automated control and then enter the manual lane under manual control following check-out. Access and egress points to and from the automated lane would be provided approximately every 3.5 kilometers at staggered check-in and check-out points along the transition lane. The need for vehicles to weave through the manual lanes to gain access to the automated facility may result in several operational problems. When the manual lanes are congested, accessibility of the automated facility would be hindered due to the difficulty in weaving through the manual lanes to access the automated facility. The capacity of the manual lanes would be reduced due to the increase in weaving activity between the right-most and left-most lanes.

Scenario 2 requires a minimum of three lanes in each direction, with automated and manual vehicles utilizing a common right-of-way. The manual and automated lanes would be completely separated with no movement between manual and automated lanes necessary or possible. The median, or left-most, lane would be the automated lane and the remaining lanes would be manual lanes. The automated lane would be completely separated from the manual lanes by a continuous concrete barrier. Since no barrier openings would exist, the movement of vehicles from the automated lane to the transition and manual lanes in the case of a blockage in the automated lane would not be possible. Therefore, an emergency lane, or shoulder, adjacent to the automated lane is recommended to allow for the continued use of the automated lane in the case of an incident in the automated lane and to provide emergency vehicle accessibility. Entry and exit to and from the automated lane would be from exclusive entry/exit facilities, consisting of ramps connected to existing or newly constructed overpasses. Due to the cost associated with designing and constructing these exclusive entry/exit facilities, it is likely that access and egress points to the automated facility would not be provided as frequently as in scenario one.

Segment 1, a 20.9 kilometer portion of Interstate 5 located in the Tehachapi mountains, between Los Angeles and the Central Valley, requires concrete barriers between the transition lane and automated lane and between the transition lane and adjacent manual lane under scenario 1. These barriers would require a minimal amount of roadway lateral expansion. Along segment portions consisting of widely separated roadbeds, steep cuts and slopes are sometimes very close to the shoulders. Where lateral expansion is required along a steep cut or slope, cost and difficulty of lateral expansion would increase. Since no additional lanes are necessary and the median width is wide enough to accommodate the required degree of lateral expansion, overpass reconstruction would not be necessary. However, where the roadbeds consist of bridge structures, if existing shoulder widths are maintained along these bridges, these structures would need to be widened slightly. Although the existing right-of-way is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

Under scenario 2, segment 1 requires concrete barriers between manual lanes and automated lanes. The addition of these barriers would require a minimal amount of roadway lateral expansion. Emergency lanes/shoulders would be required adjacent to automated lanes. The minimum number of total lanes in each direction under this scenario is three lanes. Four lanes in each direction exist throughout this segment, so either one of the existing lanes could be converted to accommodate the emergency lane/shoulder and the lane barrier or the roadway could be expanded laterally to accommodate three manual lanes, one automated lane and the required infrastructure modifications. Where access/egress lanes are required for entry/exit facilities, lateral expansion would be required within the median area, as well as some overpass modifications. Since the existing freeway right-of-way extends beyond the shoulders, needed lateral expansion could be accommodated. Where the freeway roadbeds consist of bridge structures, if the existing shoulder widths are maintained there, these structures would need widening. Although the existing right-of-way is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

For segment 2, a 16.1 kilometer portion of Interstate 5 located in the Central Valley, linking the Los Angeles area and the San Francisco Bay area, there are two lanes in each direction throughout its length with a constant and wide median. Under scenario 1, the roadway would need to be widened to accommodate two additional lanes in each direction. In addition, concrete barriers would be required for lane separation, requiring some roadway lateral expansion, though accommodated within the available median space. Under scenario 2, segment 2 would need to be widened to accommodate one additional lane in each direction with adjacent emergency lanes/shoulders plus continuous concrete barriers between manual lanes and automated lanes. The segment's wide median could accommodate this scenario.

Under both scenarios, segment 2 has the following common features. Overpass reconstruction and expansion of the existing right-of-way is not required. Along some segment portions, steep cuts and slopes are very close to the shoulders. Where roadway lateral expansion is required along a steep cut or slope, the cost and difficulty of lateral expansion would increase. Freeway roadbeds consisting of bridge structures would require significant widening. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

For segment 3, a 31.0 kilometer portion of State Route 99 between Fresno and Sacramento in northern California, the number of lanes and the median width along this segment vary significantly throughout its length. Additional lanes would be needed for the entire segment under scenario 1. Concrete barriers would be required for lane separation, requiring some roadway lateral expansion, accommodated within the available median space for most the corridor, otherwise accommodated within existing right-of-way.

Under scenario 2, segment 3 requires additional lanes along approximately 20 percent of it length. Despite the fewer number of lanes required compared with scenario 1, the roadway widths of the two scenarios would be very similar since emergency lanes/shoulders adjacent to the automated lanes would be required for scenario 2. Continuous concrete barriers between manual lanes and automated lanes would be required. As outlined above, roadway lateral expansion can be accommodated within available median space for most the corridor, otherwise accommodated within existing right-of-way.

Segment 3 for both scenarios has the following common features. In portions of this segment where lateral expansion beyond the outside shoulders is necessary, existing overpasses may not be wide enough to accommodate such expansion and therefore would need to be reconstructed. Additionally, where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), these structures would require significant widening, the extent of which varies with existing bridge widths. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

There are various trade-offs which must be considered to determine which of the two rural automated highway systems scenarios discussed is preferable. At this point in automated highway systems research, it is not possible to discern which of these two scenarios is most desirable for implementation. While it may be possible to determine which scenario is superior when comparing the two on the basis of a single criterion, such as safety, given the wide array of performance criteria which must be considered, it is not possible to make a well-informed determination of overall superiority at this time. Some of the issues which require further study include comparisons of cost, traffic operations, and safety.

Furthermore, due to the site specific nature of many of the issues, it is very difficult to make generalizations regarding the superiority of one scenario over the other. Depending upon the specific attributes of a given freeway corridor, the selection of the "best" scenario to implement may vary. For these reasons, specific recommendations for rural automated highway systems deployment are not specified. Rather, the issues and risks associated with the two deployment scenarios have been identified for further consideration.

While the issues identified and analyzed are directly related to the automated highway system deployment concepts that were examined (lane conversion, elevated structure, below-grade structure) for the case studies, they are general enough so as to provide valuable information applicable in other corridors.

INTRODUCTION FOR ACTIVITY H — ROADWAY DEPLOYMENT ANALYSIS

This report of research into Activity H, an analysis of roadway deployment for automated highway systems (AHS), investigated the issues and risks associated with AHS infrastructure deployment in both urban and rural environments. The objective is to identify potential issues and risks associated with alternative AHS infrastructure configurations likely to emerge and that need to be resolved prior to successful AHS deployment. The analysis examined several AHS infrastructure design concepts and related access and egress options. Planning restrictions such as land use constraints or environmental impacts on adjacent neighborhoods were also examined relative to the various AHS infrastructure concepts. Environmental impacts include, for example, the degree of compatibility of AHS deployment scenarios in various urban and rural settings, considering spatial requirements such as acceptable grade, lane width and physical barrier considerations and concerns such as visual effects and noise levels.

The overall conceptual structure of the research is that of an initial Baseline Study followed by Case Studies. The Case Studies involve a detailed analysis of urban and rural corridors with the objective of identifying and analyzing the roadway infrastructure-related issues and risks associated with deploying an automated highway system within the environment of those individual corridors. The Baseline Study involves the analysis of numerous California freeway corridors with the main goal of selecting the individual corridors to be investigated in the case studies.

While it was not possible to perform individual detailed case study analyses on every corridor examined in the Baseline Study, this work did allow for a deep understanding of the distributional nature of the corridor characteristics that were investigated which assisted in an initial identification of issues of importance to the infrastructure deployability of AHS, which was analyzed in more detail in the Case Studies.

This report investigated roadway infrastructure deployability issues in both urban and rural settings. Potential issues and risks likely to emerge with an automated highway system when it is integrated into existing freeway infrastructures in the State of California were identified. The initial phase of research in the urban setting focused on the analysis of California urban freeways in relation to various attributes including physical roadway characteristics, congestion, safety, and air quality to obtain an understanding of the distributional nature of these characteristics among the corridors and to select a particular urban corridor for detailed case study analysis of AHS infrastructure deployability issues. The final phase of this two phase study consists of the case study corridor analysis and evaluation of alternative AHS deployment scenarios relative to existing infrastructure configurations.

Although case study research was conducted for both urban and rural area corridors, this report focuses on the issues of automated highway systems in an urban setting, in the context of a case study of a specific urban freeway corridor in the greater metropolitan Los Angeles area, one of California's, as well as the nation's, most heavily congested region. In general, this report deals with the physical design compatibility of AHS concepts with the urban environment and to what extent such concepts can be integrated into existing freeway infrastructure configurations considering availability of land, safety of operation, and environmental concerns.

REPRESENTATIVE SYSTEMS CONFIGURATIONS

There are multiple activity areas addressed in this PSA contract. Thus, the Representative Systems Configurations are covered in the PSA Overview Report of the contract rather than in this activity area report.

Chapter 1. Baseline Study

Identification of Candidate Corridors

Urban Corridors

To identify the issues associated with roadway deployment of automated highway systems in the context of a currently existing freeway, an analysis of roadway characteristics, including for example geometric attributes, of the most heavily congested urban freeway corridors throughout the State was undertaken (San Francisco Bay Area and greater metropolitan regions of Los Angeles, Sacramento, and San Diego). These four areas represent California's four most heavily congested travel regions.[(1),(2),(3)] The Caltrans' SMART Corridor Statewide Study was an investigation of California's most heavily congested urban areas to identify those corridors where "SMART Corridor" technologies could be applied.[(3)] The original SMART Corridor is a 22.5 kilometer stretch of Interstate 10 in Los Angeles (Santa Monica Freeway) where Advanced Traveler Information and Traffic Management Systems technologies have been applied to test the feasibility of improving travel conditions for motorists in that area.

The SMART Corridor Study identified 120 corridors in the four urban metropolitan areas identified above. In identifying candidate case study corridors from this initial set, where two or more corridors were contiguous along a single route, such corridors were combined into a single corridor. In addition, corridors were lengthened to the fullest extent possible within the urbanized area boundaries identified on Caltrans' State Highway map. Differentiation between urban and rural areas was based on population as determined by the U.S. Census Bureau, with rural areas defined as geographical areas under 5,000 population, and urban areas greater than 5,000 in population. Where corridors passed through non-urbanized areas for distances of at most 3.5 kilometers (km), such roadway segments were included as part of the corridor in order to maintain the continuity of the corridor. If the break in the corridor through a rural area was greater than 3.5 km, the corridor was divided into two smaller corridors separated by the rural segments. After aggregating the initial set of corridors, a further examination was made and corridors were deleted from further consideration if they were less than approximately eight kilometers in length since it was felt that automated travel for greater than this distance was more pragmatic given the likely speed increases associated with automated vehicles. Additional urban corridors were identified within the areas under study that had not been identified by the SMART Corridor Study. A total of 52 corridors were identified ranging in length from 8.1 to 156.5 km. A more detailed description of this methodology is contained in appendix 1.

Rural Corridors

After examining the California State Highway Map, 14 rural area corridors were initially identified, linking the following California urban centers, as well as popular recreational/resort destinations, both in and out-of-state:

Greater metropolitan Los Angeles
San Francisco Bay Area
San Diego
Sacramento
Fresno, Bakersfield, and Stockton (Central Valley cities)
Redding
Lancaster/Palmdale
Palm Springs
Las Vegas
Reno

Of the 14 corridors initially identified, seven were removed from further consideration since they linked either out-of-state destinations for which data would be difficult to obtain, or did not link major urban areas. The seven remaining corridors do link major urban centers in the State for which it was felt that automated travel would be more reasonable. These seven corridors are listed in table 1:

TABLE 1. Candidate Corridors For Rural Case Studies

	Corridor	Origin-Destination Pair
(1)	Interstate 5	Los Angeles Area-San Diego
(2)	Interstate 5, Interstate 580	Los Angeles Area-San Francisco Bay Area
(3)	Interstate 5, State Route 99	Los Angeles Area-Bakersfield
(4)	Interstate 15	Los Angeles Area-San Diego
(5)	Interstate 80	San Francisco Bay Area-Sacramento
(6)	State Route 99	Bakersfield-Fresno
(7)	State Route 99	Fresno-Sacramento

Interstate = I
State Route = SR

After reviewing films for each of these seven rural area corridors from Caltrans' Photolog Film library, it was observed that fundamental differences exist between the urban and rural corridor context. In the urban setting, each corridor has similar and numerous characteristics for which it was valuable to classify to understand the constraints to AHS roadway deployment. While a detailed analysis of all urban corridors would certainly be extremely valuable, selecting only a single urban corridor would not prevent the discovery of numerous, if not all, issues that were relevant and valuable across the entire urban freeway corridor landscape. In the rural setting, however, while the corridors have some features in common, important differences also exist between the corridors relative to their roadway characteristics. Therefore, selecting a single rural corridor would not allow for a complete analysis of important features. The plan was to first categorize the seven rural corridors by common features, then select segments of corridors from each of the identified categories for detailed analysis.

Criteria for Corridor Classification

Urban Corridors

For each of the 52 urban corridors identified, the primary roadway characteristics that represented potential constraints to the accommodation of an automated highway facility were identified by reviewing films of these corridors from Caltrans' Photolog Film library. Filming for the corridors under investigation was performed between 1989 and 1992. Physical features consisted of the following:

- vehicle overpasses
- pedestrian overpasses
- railroad overpasses
- soundwalls
- retaining walls
- frontage roads
- land use restrictions
- tunnels

Land use restrictions included constraints such as structures (residential, commercial, or industrial), parking lots, bodies of water, and rail lines. In general, the presence of the fourth through seventh characteristics above were deemed to be constraints if they were not adequately set back beyond the outside shoulder to allow for the addition of a 3.1 to 3.7 meter traffic lane. Even if sufficient space were available between the outside shoulder and such roadway characteristics, if the steepness of a cut or slope in this area could cause a problem if graded, such as in a case where an embankment is supporting a soundwall on top of a slope, then this situation was considered a restriction and was identified as such. The presence of High Occupancy Vehicle (HOV) lanes was also identified as HOV lanes are a special-use facility and could serve as a model for the deployment of an AHS.

The type of terrain through which the corridors pass was also noted since the natural terrain of a roadway alignment significantly affects the ease and cost of roadway expansion. For example, highways which pass through very hilly topography typically require significant cutting and filling to meet horizontal and vertical curve standards throughout the length of the highway. Furthermore, depending upon the steepness of the cuts and slopes and the specific soil characteristics, it may be necessary to construct expensive retaining walls to accommodate highway expansion. Five terrain types were identified as follows:

- very flat
- fairly flat to gently rolling
- moderately hilly and rolling
- hilly with a significant amount of steep slopes
- very hilly with many very steep slopes

A detailed description of the methodology used in reviewing the Caltrans Photolog and the constraints to its use in the corridor analysis are contained in appendix 2 and 3, respectively.

Emphasis on the physical features of the corridors is reasonable since the study's primary objective was the analysis of roadway infrastructure deployability issues. Other corridor characteristics, such as congestion, safety, and air pollution, while of lesser importance relative to physical features for AHS roadway deployment, were also included in the case study corridor selection process to produce a more complete corridor profile because of their importance relative to existing roadway conditions.

The measure of congestion used was determined primarily by data availability for the entire length of each corridor and is represented by the following expression: $AADT/(C_L*L)$, where AADT = annual average daily traffic, C_L = hourly lane capacity, and L = number of lanes. The conventional value of 2,000 passenger vehicles per hour per lane was used for the hourly lane capacity. Past studies have found a relationship between this measure and levels of congestion, indicating that a value of 9 for this measure corresponds to the threshold for Level of Service (LOS) F freeway congestion.(4) The measure of safety used was the accident rate (total accident volume per million vehicle kilometers traveled (MVKT)).(1) The air pollution measure considered was the number of days in 1992 in exceedance of federal standards for ozone, carbon monoxide (CO), and oxides of nitrogen (NOx).

Rural Corridors

For the seven rural area corridors, the following characteristics were examined to classify the corridors by type: (1) terrain, (2) median attributes, (3) land use restrictions, and (4) overpass characteristics.

Corridor Classification and Analysis

Description of Roadway Corridor Characteristics for Urban Corridors

An initial analysis of the urban corridors was performed to ascertain which roadway characteristics were the most representative among the corridors and the degree of diversity of these characteristics among the corridors. Twenty-four of the 52 corridors were eliminated from further examination due to a lack of diversity and representativeness of these roadway characteristics. All corridors that possessed at most four of the nine physical features listed above were eliminated. Of the nine physical characteristics (eight aforementioned attributes plus presence of HOV lanes), the following six physical features were common to at least half of the fifty-two corridors and were therefore considered the most representative physical features: vehicle overpass, pedestrian overpass, soundwall restriction, retaining wall restriction, land use restriction, and frontage road restriction. Some corridors, though not all, that possessed only a limited number, e.g. three or four, of these most representative features were also deleted from further consideration. A more detailed description of the methodology used in this first stage elimination process is contained in appendix 4.

Urban Corridor Classification and Distributional Analysis

The 28 remaining corridors were then classified relative to all 9 roadway characteristics. Two additional physical features, namely number of lanes per direction and median width were also included in the analysis. Data sources used for the corridor classification were Caltrans' 1989 through 1992 film logs for each corridor under study. Median width and number of lanes was based on information contained in the 1992 California State Highway Log Reports corresponding to the corridors under study.[5] A more detailed discussion of the methodology of this analysis is contained in appendix 5. The primary question during this corridor analysis was the following: What percentage of corridors have a certain characteristic over what portion of corridor length? Figures 1 through 11 depict the cumulative frequency distributions for each of the roadway features under examination. Such graphical depictions of the data allow the above question to be answered. Using cumulative frequency distributions allows for a quantitative understanding of the distribution of each of the roadway characteristics among the corridors under study. Understanding the distributional nature of all these characteristics among the corridors assist in the task of identifying issues and constraints associated with deploying particular AHS infrastructure configurations.

The exact location of each type of overpass (vehicle, pedestrian, and railroad) for each corridor was identified. From this data, the density (number of overpasses/kilometer) of each overpass type was derived. These statistics assisted in determining the issues associated with utilizing an elevated structure for an automated highway facility. The average density for vehicle, pedestrian, and railroad overpasses were respectively, 0.68, 0.06, and 0.02 per kilometer. Thus vehicle overpasses would generally pose more of a constraint to AHS deployment than the other overpass types. The cumulative frequency distribution for the vehicle overpass density measure is depicted in figure 1. While the maximum vehicle overpass density measured was 1.57, over 80% of the corridors have a vehicle overpass density at most 0.74. The maximum pedestrian overpass density measured was 0.25, or one overpass per four kilometers. The maximum railroad overpass density measured was 0.22, or one overpass per 4.5 kilometers. The cumulative frequency distributions for the pedestrian and railroad overpass densities are depicted in figures 2 and 3, respectively.

The percentage of each corridor for each direction (the directional corridor) containing such features as retaining walls, soundwalls, frontage roads, and other land use restrictions were identified. These statistics assisted in determining issues associated with expanding the total traveled-way and possibly the right-of-way (ROW) to accommodate an automated highway facility. The percentage of corridor lengths averaged over each direction for each corridor containing restrictions to lateral roadway expansion due to retaining walls, soundwalls, frontage roads, and land uses were 2.0, 8.1, 4.8, and 4.7, respectively. Thus, 8.1% is the average percentage of total corridor length containing soundwall restrictions of the fifty-six directional corridors (28 corridors, 2 directions/corridor). The cumulative frequency distribution for the percentage of directional corridor length containing soundwall restrictions is depicted in figure 4. While the maximum percentage of corridor length for a single direction containing soundwall restrictions is 63.5%, over 90% of the directional corridors have soundwall restrictions over at most 20% of their length. Thus, soundwalls would only be a moderate constraint to lateral roadway expansion to accommodate an automated highway facility. The cumulative frequency distribution for the percentage of directional corridor length containing the other features is depicted in figures 5 through 7. Since the remaining physical features (restrictions to lateral expansion due to retaining walls, frontage roads, and land uses) have substantially smaller maximum percentages of corridor length coverage, these features would be even less of a constraint than soundwalls to lateral roadway expansion to accommodate an automated facility.

Only 4 of the 28 urban corridors studied possessed a tunnel, covering at most 1% of the length of any individual corridor (figure 8). Approximately 46% of the corridors have no HOV facility at all, and the remaining corridors have an HOV facility covering an average of 31.3% of their length per direction (figure 9).

The percentage of total corridor length over which space exists within the median for additional lanes is another important measure since deploying an automated highway facility within the median area would minimize the need to build elevated structures and to acquire additional ROW to accommodate additional at-grade lanes. The average percentage corridor length over which sufficient space exists for a total of at least one, two, and three lanes within the median is 82.5%, 42.1%, and 26.2%,

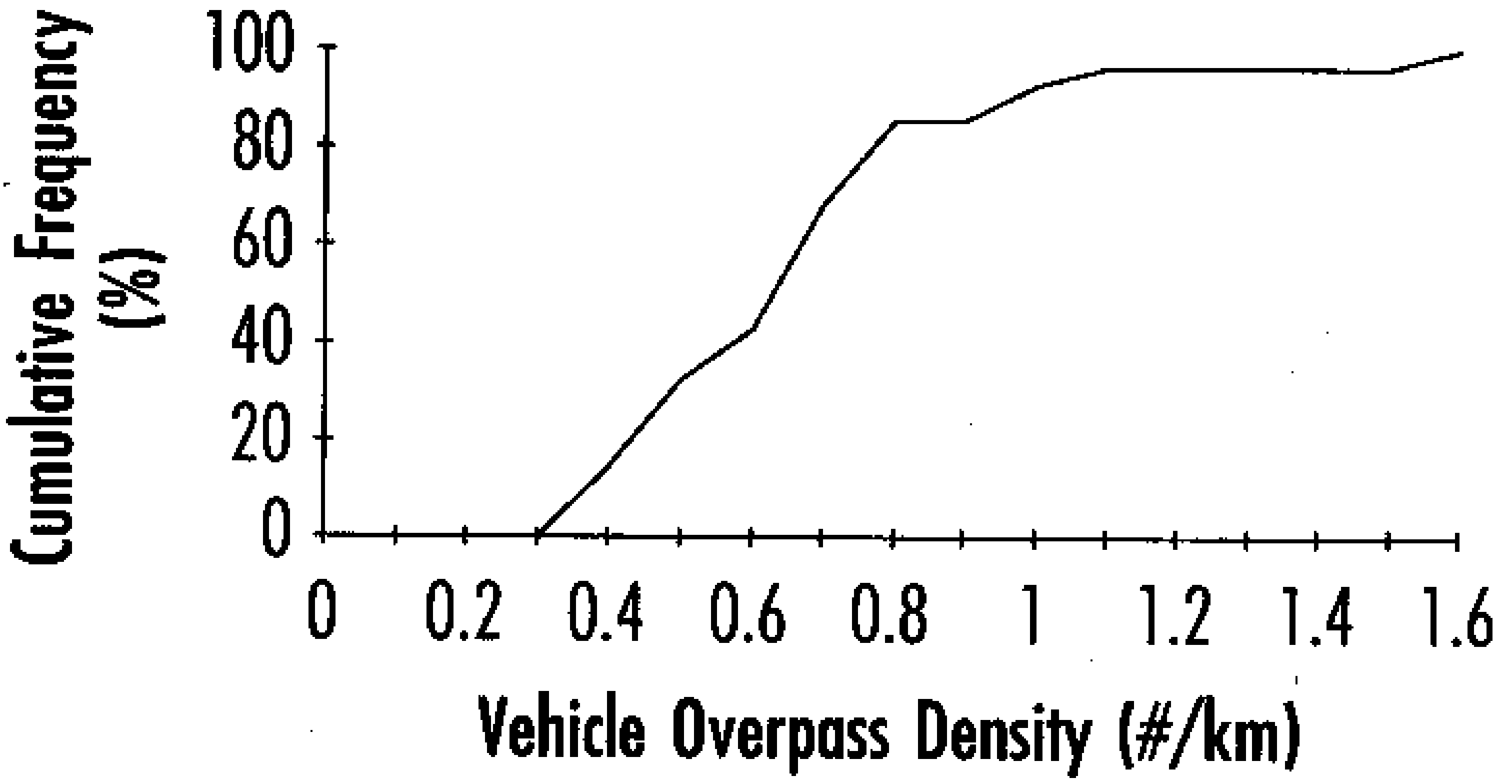


Figure 1. Cumulative Frequency Distribution for Vehicle Overpass Density

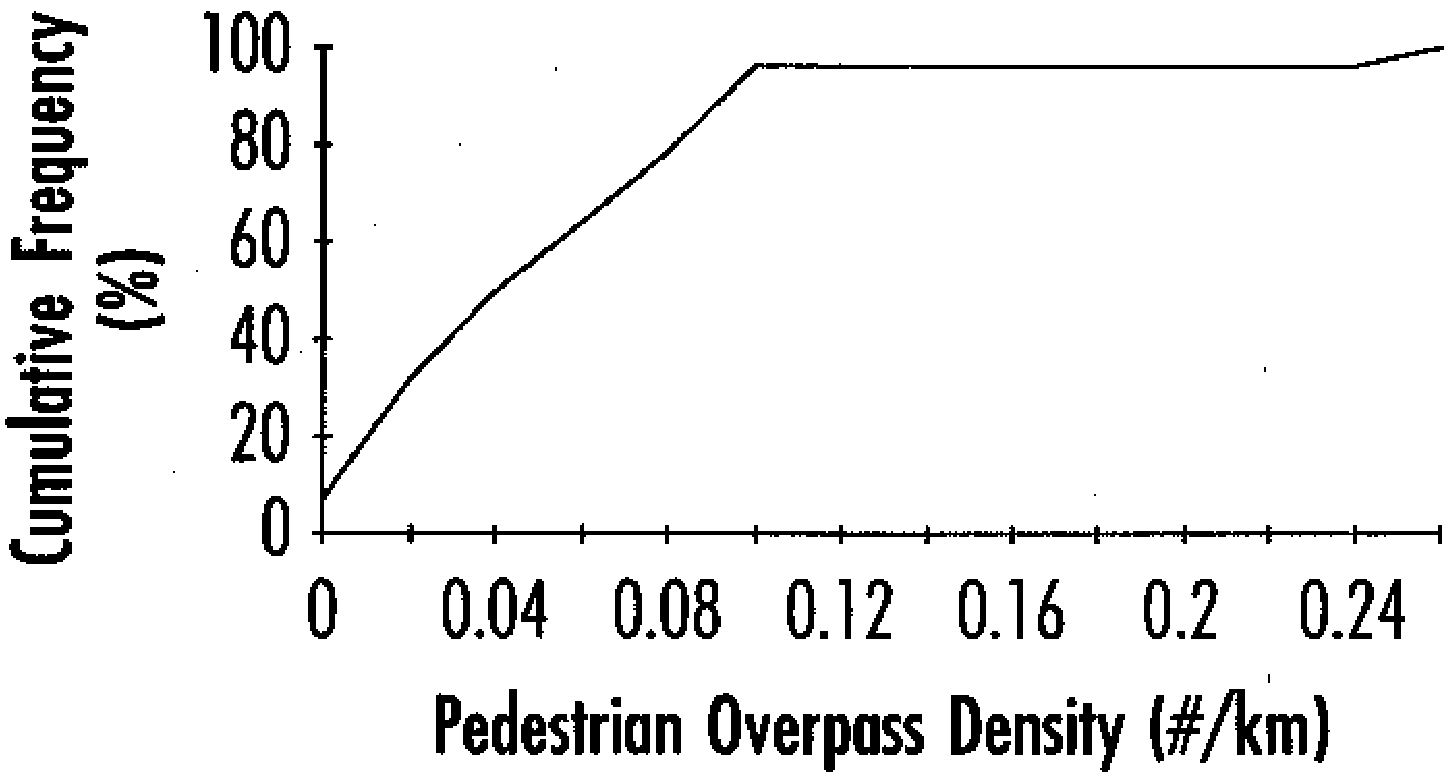


Figure 2. Cumulative Frequency Distribution for Pedestrian Overpass Density

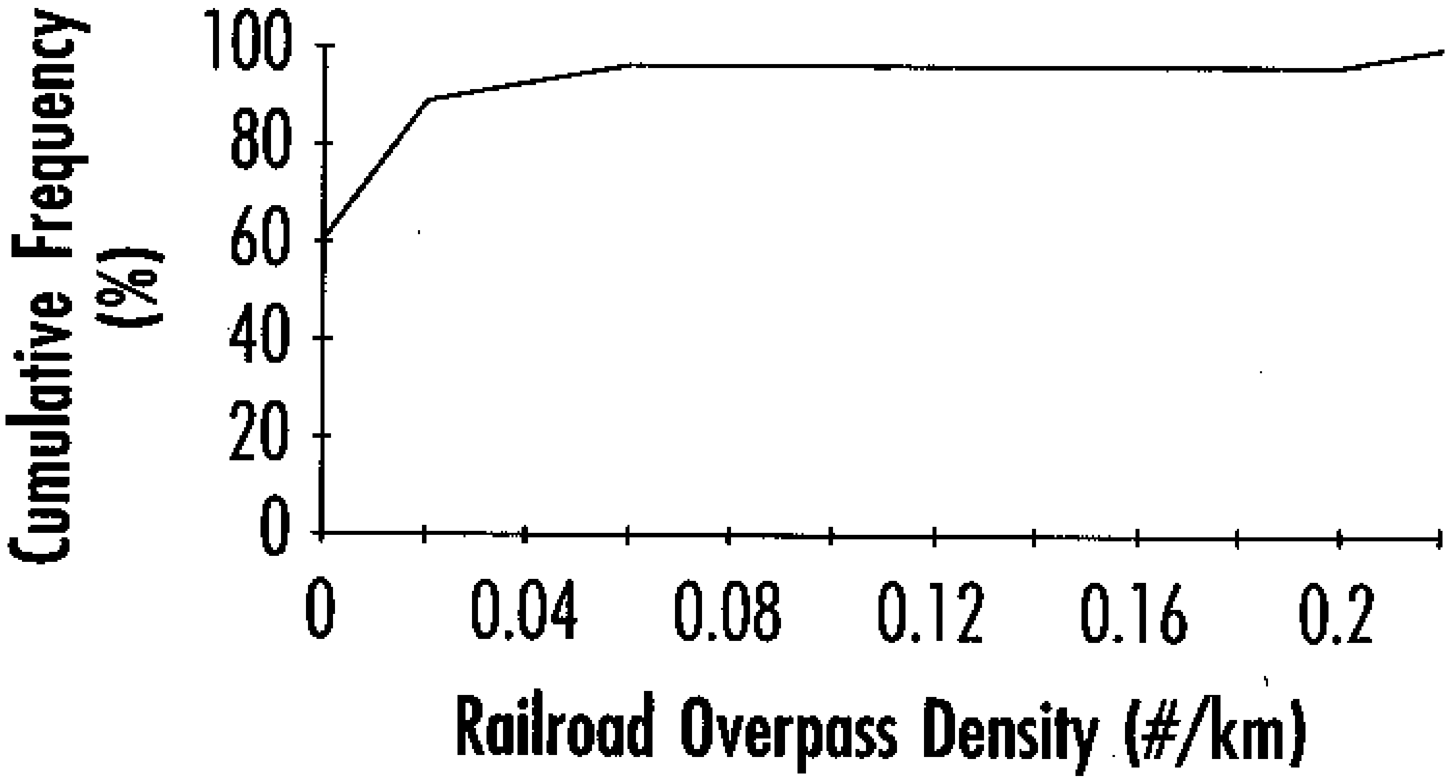


Figure 3. Cumulative Frequency Distribution for Railroad Overpass Density

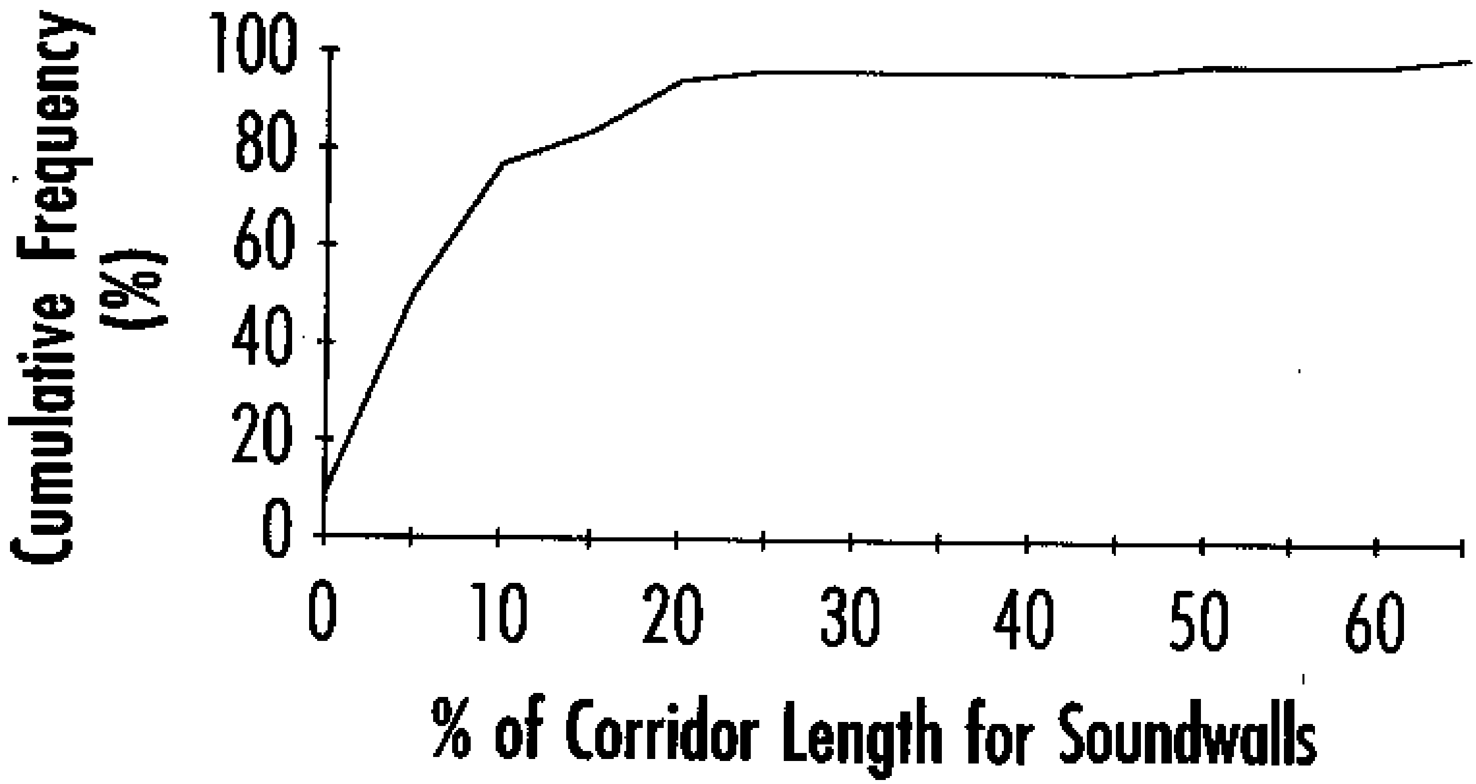


Figure 4. Cumulative Frequency Distribution for Percentage Corridor Length for Soundwalls

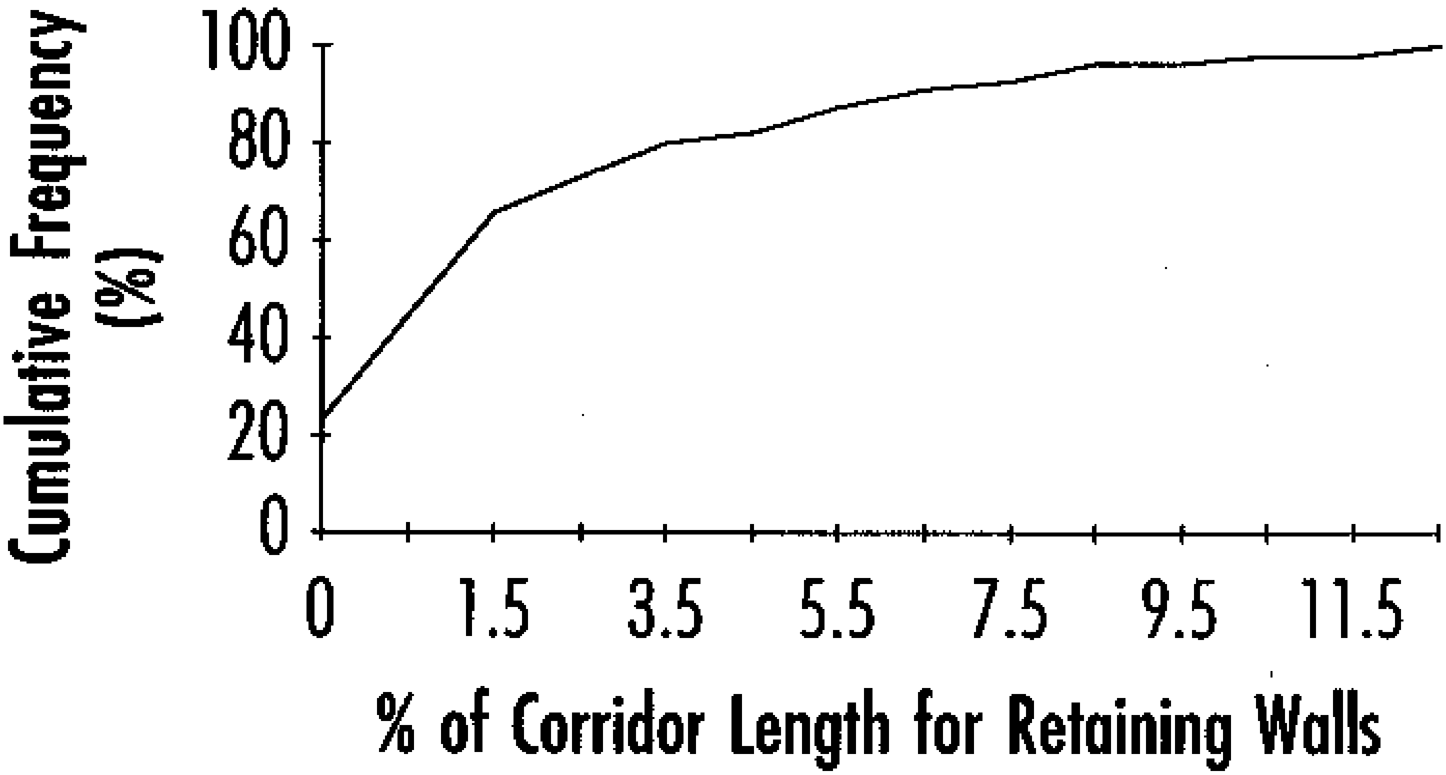


Figure 5. Cumulative Frequency Distribution for Percentage Corridor Length for Retaining Walls

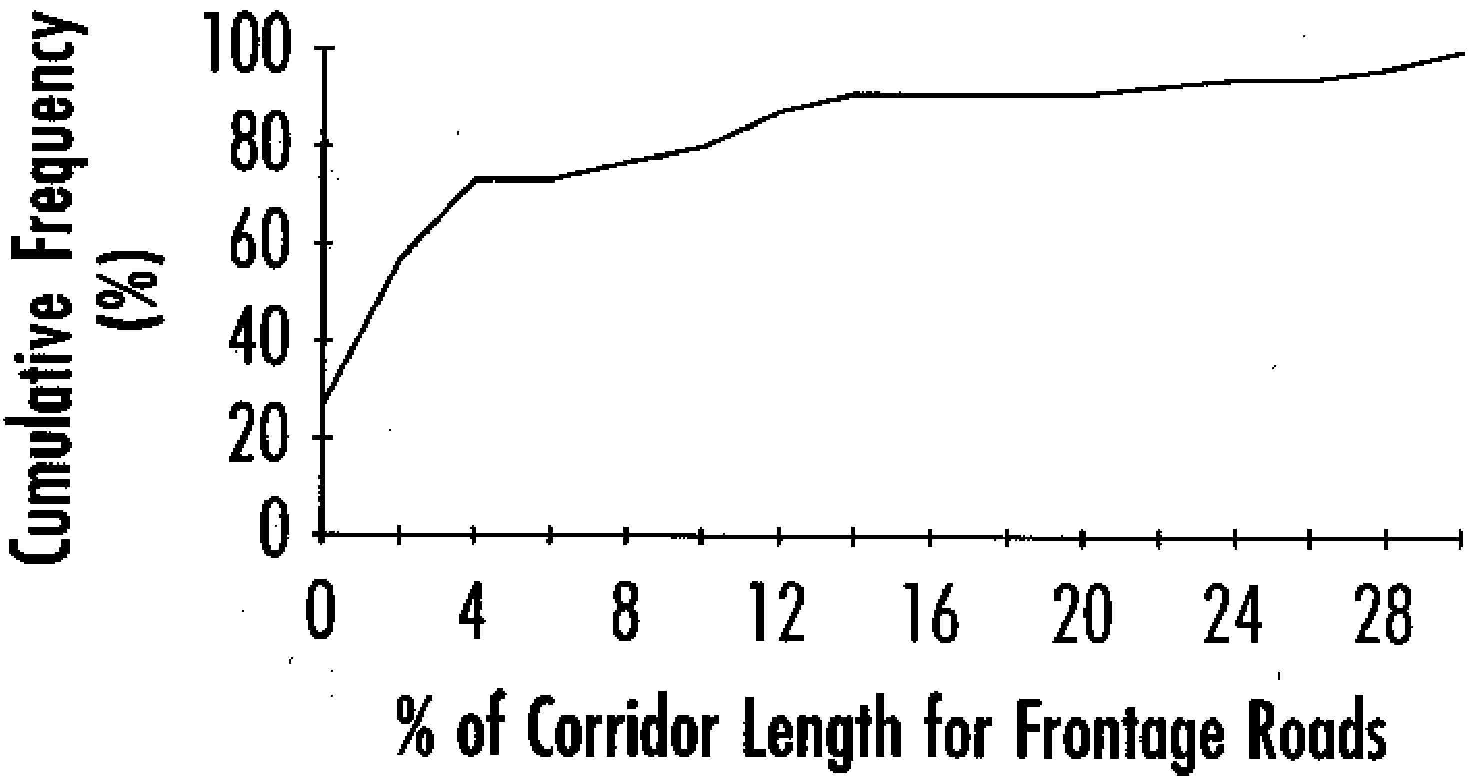


Figure 6. Cumulative Frequency Distribution for Percentage Corridor Length for Frontage Roads

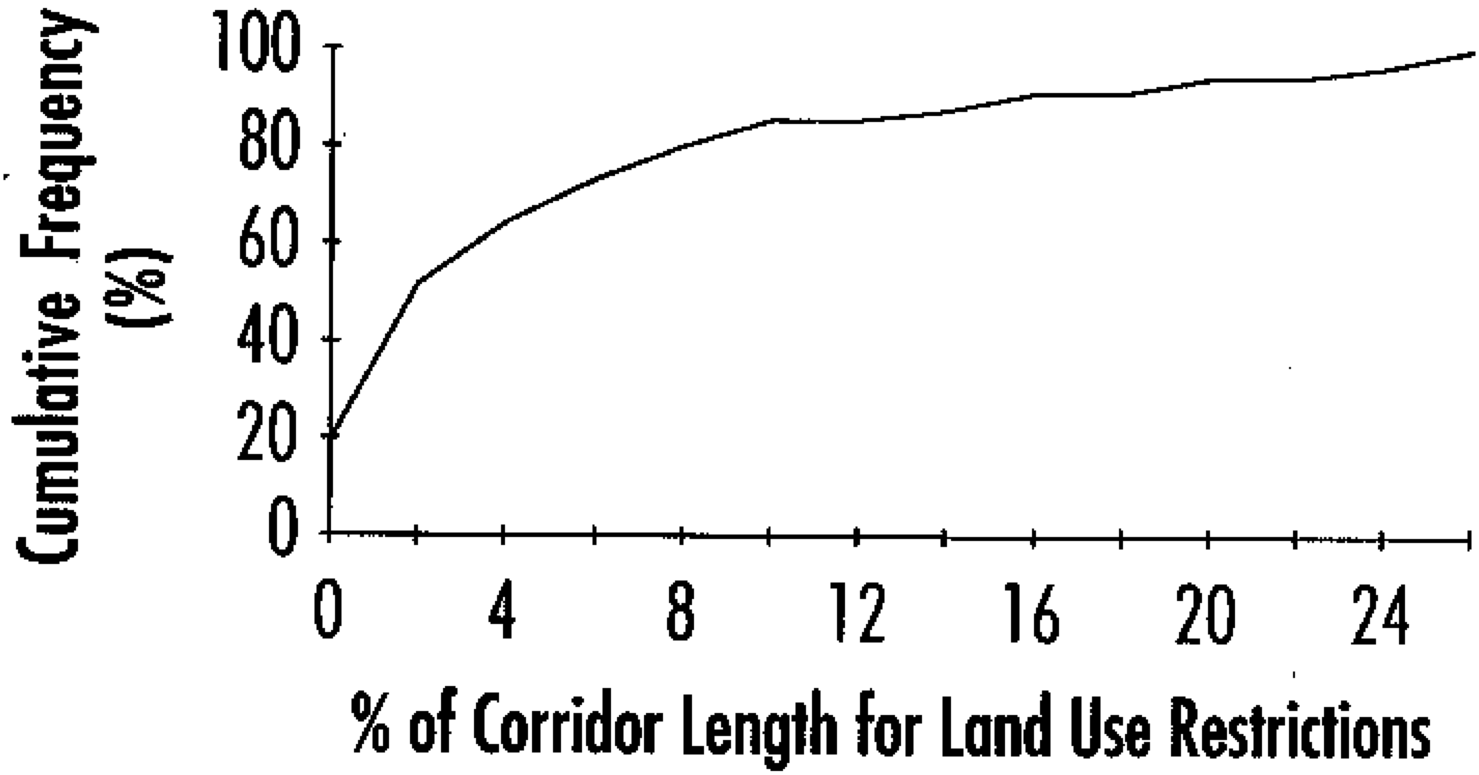


Figure 7. Cumulative Frequency Distribution for Percentage Corridor Length for Land Use Restrictions

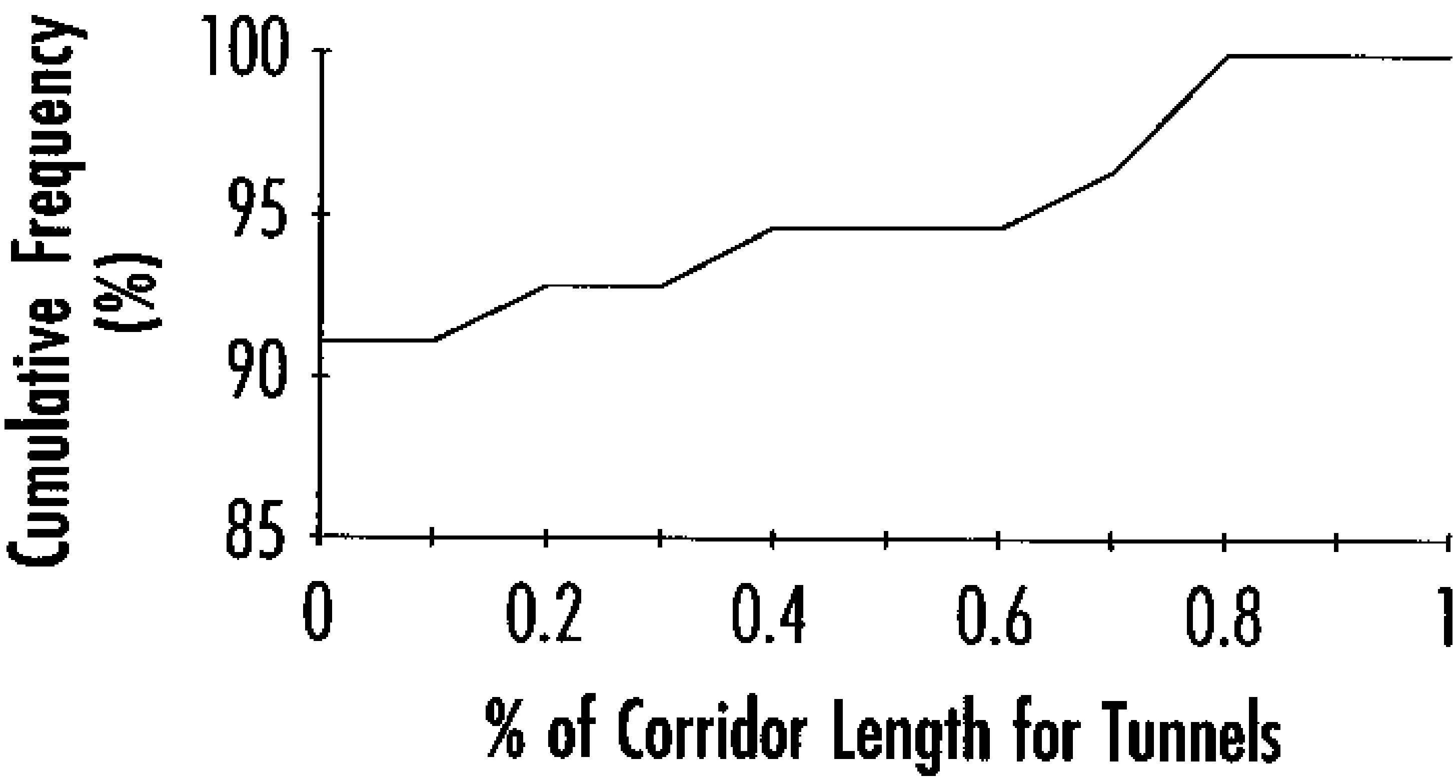


Figure 8. Cumulative Frequency Distribution for Percentage Corridor Length for Tunnels

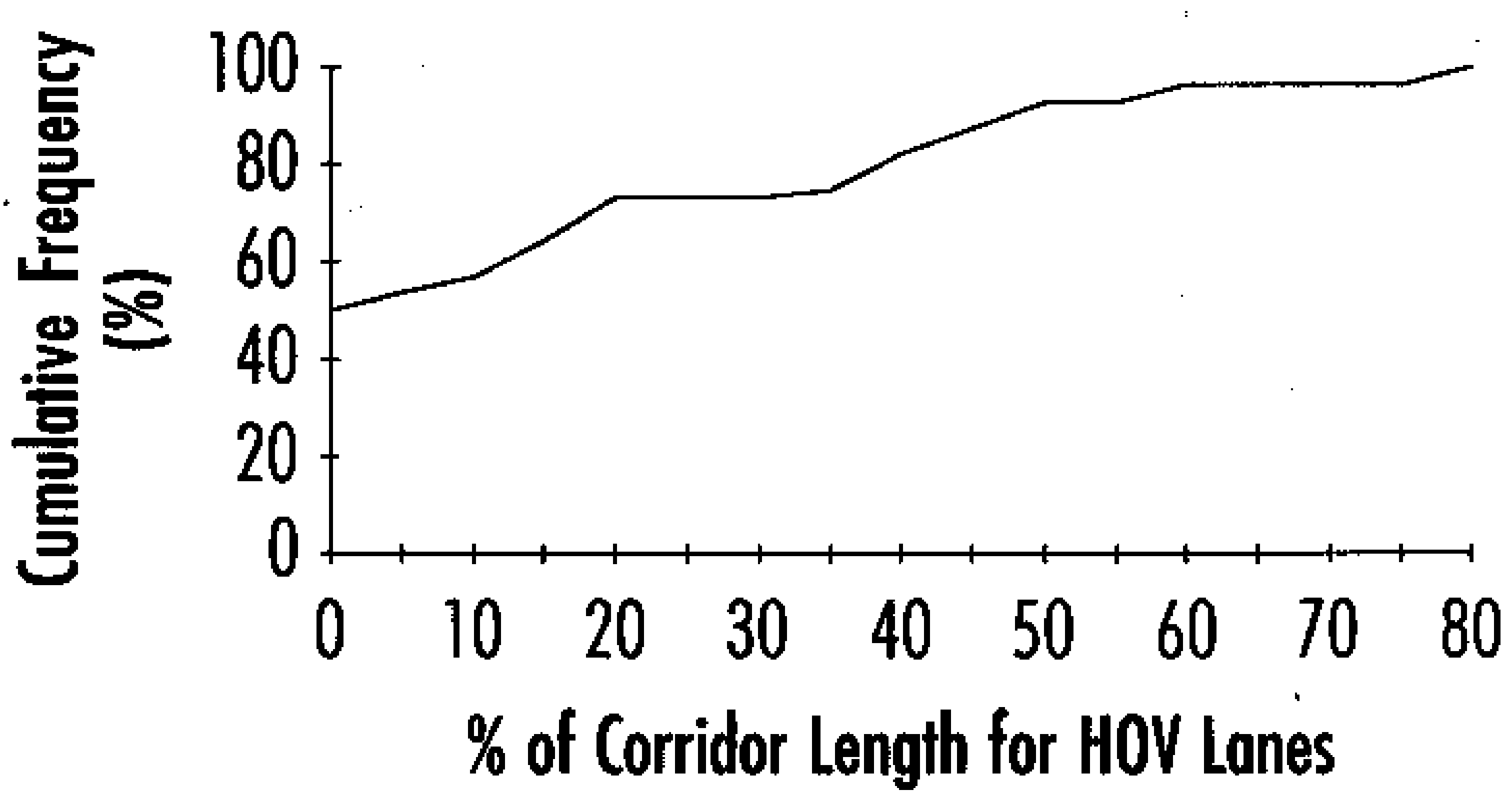


Figure 9. Cumulative Frequency Distribution for Percentage Corridor Length for HOV Lanes

respectively. A standard lane width of 3.7 meters and a median width of 1.2 meters was assumed in this analysis. The cumulative frequency distributions for the percentage of total corridor length containing enough space for at least one, two, and three lanes within the median area is depicted in figure 10. As the number-of-lanes-within-the-median requirement increases, the corridor percentage length over which such space exists decreases, as reflected in the upward and leftward shift in the distributions. The one-lane-in-the-median distribution indicates that approximately 54% of the corridors have such space over at least 90% of their length, and 28.6% of the corridors have such space over their entire length. Thus, usage of available median space for at least one additional lane is a viable option to consider.

The percentage of total corridor length over which exists a particular number of lanes is another important measure since the deployment of various AHS configurations require a minimum number of lanes. The average percentage corridor length for which there exists at least four and five lanes in each direction is 61.7% and 16.9%, respectively. The cumulative frequency distributions for the percentage of total corridor length containing at least four and five lanes in each direction is depicted in figure 11. As the number-of-lanes-in-each-direction requirement increases, the corridor percentage length over which this number of lanes exists decreases, as reflected in the upward and leftward shift in the distributions. The four-lanes-per-direction distribution indicates that approximately 32% of the corridors possess this attribute over at least 80% of their length. Whereas, the five-lanes-per-direction distribution indicates that approximately 90% of the corridors have such an attribute over at most 30% of their length.

The analysis of the terrain type indicated that approximately 36% of the corridors had terrain type limited to either very flat or gently rolling features, whereas approximately 61% of the corridors possessed the full spectrum of terrain types, from very flat to very hilly with many very steep slopes. A detailed description of the values for the nine physical features for each of the 28 urban area corridors is contained in appendix 6.

Other Urban Corridor Classification Criteria

Congestion data was available only for corridor segments over which roadway geometric characteristics remained constant, such as the number of lanes, subsequently requiring data aggregation to derive a corridor-wide value for the congestion measure.[2] The expression, AADT/(2,000*L), was calculated for each corridor segment, then a weighted average measure of congestion for the whole corridor was calculated with each segment weight equal to that segment's percentage of total corridor lane-kilometers. The average congestion measure value over the 28 urban corridors was 10.6, while over 70% of the corridors (20/28) had a congestion measure value greater than 9, the threshold for LOS F traffic conditions. The lowest measure value was 6.7. Both the total number of accidents and MVKT were available per corridor segment, allowing the calculation of the accident rate for the entire corridor.

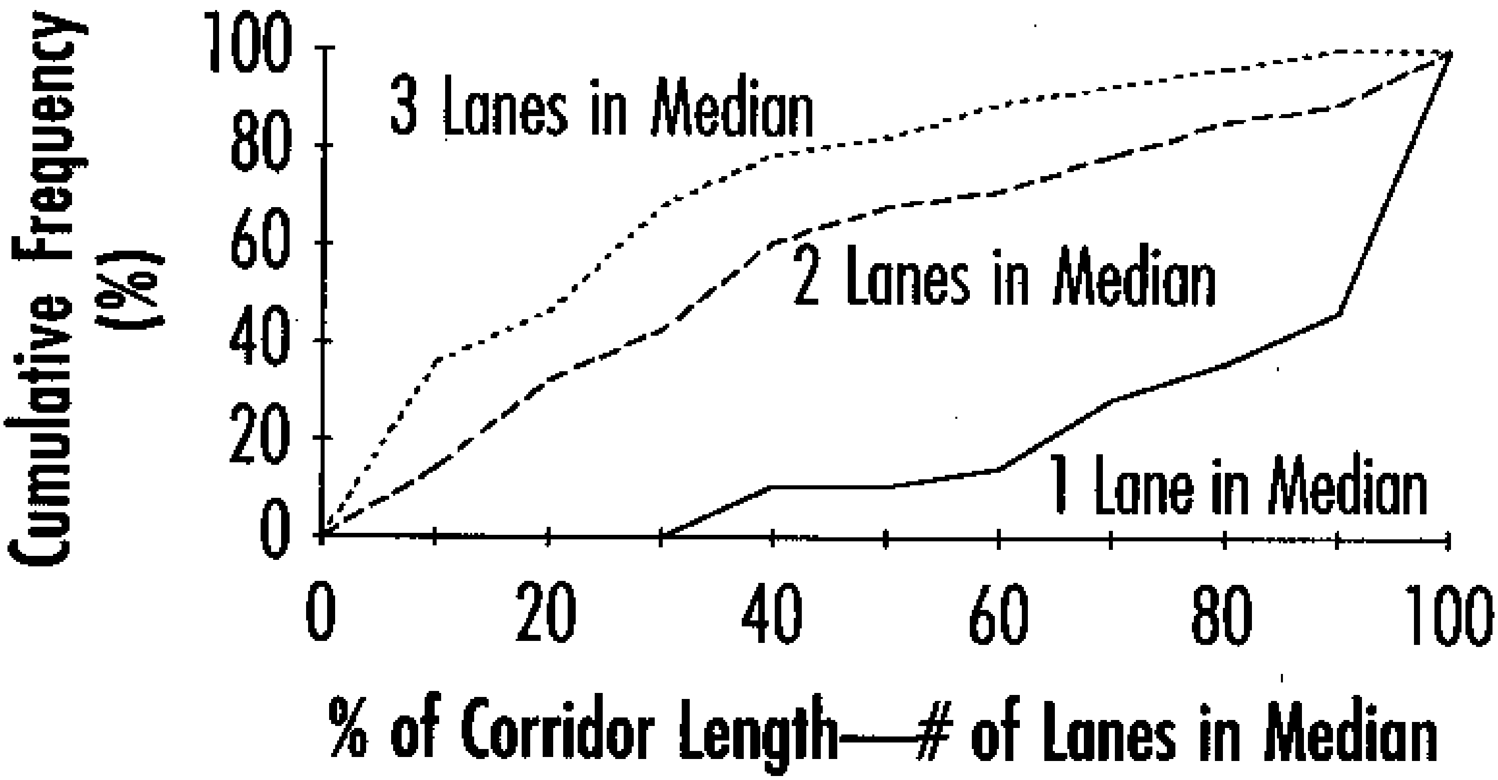


Figure 10. Cumulative Frequency Distribution for Percentage Corridor Length—Number of Lanes in Median

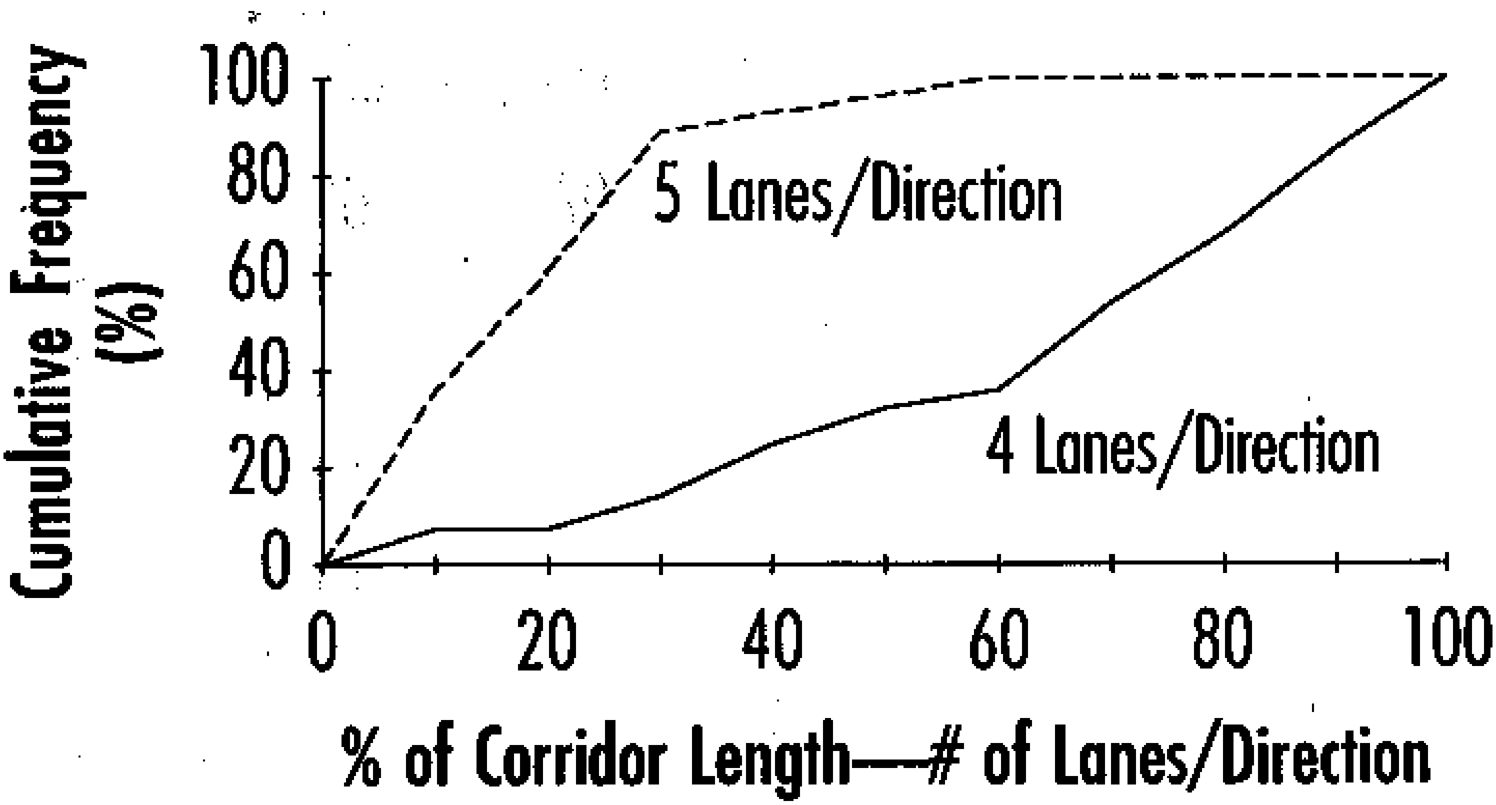


Figure 11. Cumulative Frequency Distribution for Percentage Corridor Length—Number of Lanes/Direction

Data was, however, incomplete and not precise enough to confidently quantify an air pollution profile for each corridor without making numerous assumptions to fill in the information gaps. Data fell into the following three categories: (1) regionwide statistics of compliance with federal standards for a particular pollutant, for example, San Diego met federal standards over the entire region for CO and NOx throughout the year,[6] (2) statistics on the number of days in which the federal standard for a pollutant was exceeded by air quality monitoring station location, and (3) no data on the number of days federal standards were exceeded for a pollutant. Category 2 data along with monitoring site locations were available on regional maps. Corridor locations within the region were overlayed on these maps to attempt to determine which portions of a corridor corresponded to certain air quality data. For example, one corridor is Interstate 5 in metropolitan Los Angeles and corresponded to a range of between 0 and 60 days of exceeding federal CO standards. The ability to accurately estimate the distribution of this measure along the full corridor length depended on having a sufficient number of monitoring station locations to help "connect the dots" formed by the available monitoring stations, which was not always available. Without such information, an accurate corridor estimate for this measure could not be derived. For Category 3 data, assumptions would have to be made to make estimates. For example, no San Francisco Bay Area data was available for NOx or CO, however, the Los Angeles region had a maximum of 3 days exceedance of federal standards for NOx and San Diego had zero days exceeding federal standards for CO in 1992. Since Los Angeles' air quality is the worst in California, and the Bay Area's is generally the best, among major metropolitan areas, it was assumed that the latter had zero days of federal standard exceedance for both NOx and CO. Other such assumptions were made to fill in the data gaps. As is described below in the discussion on the development of the corridor ranking scheme, the air pollution measure had no effect on the final selection of the urban case study corridor (a corridor in Los Angeles). In fact, since Los Angeles air is of the poorest quality in the State, one would expect a bias in favor of Los Angeles area corridors based on the corridor characteristic prioritization and ranking scheme which was based on selecting the "worst" case corridor, i.e. the corridor with the most overall constraints to AHS infrastructure deployment.

Rural Corridor Analysis

After reviewing the final seven rural area corridors, three corridor categories were discerned based on qualitative differences among the physical features previously listed.

Type 1 Characteristics

Terrain is generally flat to rolling hills. Median widths are fairly wide and suitable for roadway expansion, with some exceptions in hillier areas which contain separated roadbeds and therefore generally unusable median areas. No land use restrictions exist, and there are very few land uses in existence along this corridor type other than occasional traveler services near freeway-to-freeway interchanges. Adjacent lands typically consists of fallow and cultivated farmlands and scrubbrush vegetation. Frontage roads are occasionally located alongside the corridor. Vehicle overpass densities range from 0.09 to 0.31 overpasses per kilometer. Portions of corridors 1, 2, 3, and 5 are of this type (table 1).

Type 2 Characteristics

Similar to Type 1 with the notable exceptions that portions of the corridor pass through mountainous terrain and median widths range from narrow to fairly wide. Portions of corridors 2 through 5 are of this type (table 1).

Type 3 Characteristics

Terrain is very flat throughout the corridor. Median widths range from narrow to fairly wide, with occasional short segments containing little or no available median space for lateral roadway expansion. Scattered rural land uses as well as dense urban land uses adjacent to the freeway pose only minor restrictions to lateral roadway expansion. Frontage roads and soundwalls are present alongside portions of this corridor type, posing a restriction to lateral roadway expansion in places. Railroad lines are frequently located adjacent to long portions of the highways, although they do not appear to pose a restriction to lateral roadway expansion. In addition, cultivated farmlands exist along major portions of this corridor type. Land uses are generally clustered within the boundaries of small urban communities which the corridors pass through. Some portions of these corridors are not full-access controlled freeways and contain at-grade intersections, U-turn zones, and "tight" access and egress points with no accompanying on- and off-ramps. Vehicle overpass densities along these corridors range from approximately 0.12 to 0.71 overpasses per kilometer, and are generally uniformly distributed throughout each corridor. Corridors 6 and 7 are of this type (table 1). A detailed description of the corridors evaluated is contained in appendix 7.

Development of Corridor Ranking Scheme

Urban Corridor

The objective in selecting the urban case study corridor was to choose, to the extent possible, the "worst" case corridor, that is, the corridor that presented the greatest challenge to AHS roadway deployment. If viable AHS deployment alternatives could be identified for this corridor, other corridors might be more responsive to the resolution of their own roadway deployment issues. In terms of the physical features, "worst" case corridor features refer to the following:

- greater overpass densities
- greater presence of restrictions to lateral expansion with restrictions such as from soundwalls, retaining walls, and other land use constraints, measured by the percentage of directional corridor lengths with such constraints
- little or no provision of dedicated lanes for high occupancy vehicles
- more hilly and steep terrain
- narrower median width, expressed as a smaller percentage of corridor length over which median space exists for additional lanes, usually one, two, or three

- fewer number of lanes, expressed as a smaller percentage of corridor length over which there are a particular number of lanes, usually four or five.

The greater the value for the congestion, safety, and air pollution measures corresponded to a "worst" case corridor for these characteristics.

Thus for each corridor, physical features, congestion, safety, and air pollution attributes were used to select the case study corridor. The initial step was to translate each attributes' data to a common ordinal scale to rank the corridors and compare them across different attribute measures. Several ranking schemes were evaluated to determine differences, if any, in the selection of the case study corridor. While there was small variation among the relative rankings among the corridors by ranking scheme, the selected corridor always retained its number one ranking. All the ranking procedures were basically the same, with relatively small variations among them. One such ranking scheme is described in detail, along with such variations.

The 28 urban corridors were ranked in order from 1 to 28, with one being highest, i.e. "worst" case, for each of the physical features, congestion, safety, and air pollution measures. Ties were assigned the average value of the ordinal ranking. For example, the "worst" value, i.e. maximum value, for vehicle overpass densities among the corridors was 1.57 and was assigned the value one. For the percentage corridor length over which there was available median space to accommodate one additional lane, the highest ranked corridor here corresponds to the minimum value (36.1%), while the eight corridors having sufficient median width for an additional lane along their entire lengths would be given lower rankings and are thus assigned the average ranking of 24.5 (average of 21 through 28).[1] After the corridors were ranked for each geometric characteristic, a single geometric attribute value was derived for each corridor by calculating the simple average over all physical features. The method of aggregating all the physical features' data, in this case using a simple average, was one part of the ranking scheme allowed to vary. At this stage in the selection process each corridor had ranking values for the following four characteristics: physical features, congestion, safety, and air pollution, each on a scale from one to twenty-eight. The final step in aggregating the data was the assignment of weights among these four characteristics. The physical features, congestion, safety, and air pollution rank values for each corridor were assigned the weights, 0.6, 0.2, 0.1, and 0.1, respectively. Because of the significance of the physical features, this rank value was substantively greater than the other three weights. The set of ranking weights was another part of the ranking methodology allowed to vary, subject to the above constraint on the physical features' rank weight. Different ranking schemes were evaluated, leading to small changes in the relative corridor rankings, except the corridor

---

[1] Alternatively, a scale of 1 to 10 was also used for each characteristic, which resulted in some information loss because of the aggregation of 28 values into ten categories. The highest ranked value for each characteristic, e.g. 1.57 for vehicle overpass density, was used to derive the values for every other category boundary value. For example, 1.41 (90% of 1.57) corresponds to "2" on the 1-to-10 scale, 1.26 (80% of 1.57) corresponds to "3" on the scale, and so on.

ranked number one retained its highest ranking. It was not true, however, that the highest ranked corridor was highest ranked in every category.

Another variation in the ranking schemes was to exclude the air pollution measure in the calculation. As previously described, since the data was fragmentary depending on numerous assumptions to establish a complete data set, as well as the general expectation that since Los Angeles air pollution is the State's poorest, including air pollution would only tend to bias the corridor ranking in favor of Los Angeles area corridors. The final step in aggregating the data into a single "score" was altered to exclude the air pollution measure. The reassigned weights for physical features, congestion, and safety measures were 0.6, 0.2, and 0.2, respectively. After scoring the corridors, small changes resulted in the relative corridor rankings, with no change in the highest ranked corridor.

Rural Corridors

No ranking scheme was devised for the selection of rural area corridors as previously stated.

Selection of Corridors for Case Studies

Urban Corridor

The number one ranked corridor and choice for the case study was U.S. Route 101 in Los Angeles spanning 52.3 kilometers from the Los Angeles Central Business District through Hollywood to the western end of the suburban San Fernando Valley area of

Los Angeles (Los Angeles County PM S0.00 through 31.05)[2].

Rural Corridors

Portions from each of the three identified corridors types were selected for the case study analyses as follows:

Type 1 case study corridor section: A 16.1 kilometer portion of corridor 2 (I-5) located in the Central Valley, linking the Los Angeles area and the San Francisco Bay area.

---

[2]The post mile designation, S0.00 - 31.05, consists of two components, namely S0.00 through S1.32 and 0.00 through 31.05 for a total of 32.4 miles, or 52.3 kilometers. New post mile values are assigned whenever a length of highway is changed due to construction or realignment. To differentiate the new values from the old, an alphabetic prefix code is added to the post mile for the new values. The prefix code for the first 1.32 miles of this corridor, i.e. "S" indicates the construction of roadway designated as a spur.

Type 2 case study corridor section: A 20.9 kilometer portion of corridor 3 (I-5) located in the Tehachapi mountains, between Los Angeles and the Central Valley.

Type 3 case study corridor section: A 31.0 kilometer portion of corridor 7 (SR-99) between Fresno and Sacramento in northern California.

Chapter 2. Urban Case Study

Description of Urban Case Study Corridor

Overall, the urban case study corridor, U.S. Route 101 in Los Angeles, possessed the "worst" set of values for its roadway, congestion, and safety characteristics relative to the other urban corridors examined, i.e., providing overall the greatest degree of potential constraints to the accommodation of an AHS facility. Vehicle, pedestrian, and rail overpasses were present along this corridor with the following average frequencies: 0.7 vehicle overpasses per km, 1 pedestrian overpass every 17.9 km, and one rail overpass every 48.4 km. Lateral restrictions, such as soundwalls, retaining walls, frontage roads, and other land use constraints are present over a percentage of the corridor length ranging from 1% to 9%. There were neither tunnels nor HOV lanes along this corridor. Median width availability for one additional 3.7- meter lane (in total, not in each direction) existed over approximately 36% of the corridor length. The number of lanes in each direction varied predominantly between four and five throughout the corridor. The corridor's terrain ranged from very flat to hilly areas with steep slopes. This corridor was the most congested and had the second highest accident rate of all corridors examined.

In the San Fernando Valley, the majority of the roadway is built on a continuous berm with some space within the median and beyond the outside shoulder available for expansion of the roadway. Four or five lanes in each direction and frequent overpasses are typical along this portion of the corridor. As dictated by the raised berm, resulting in the elevation of the freeway roadbed being higher than the elevation of the local street network, underpasses are typical along this portion of the corridor and are connected to frontage roads. Landscaping along the slope of the berm provide some degree of visual and noise buffering between the freeway and the adjacent residential and commercial land uses. A unique condition of the selected corridor is the segment between the San Fernando Valley and Hollywood where right and left lane freeway splits and merges are present to accommodate continuous travel as well as freeway-to-freeway movements among Routes 101, 134, and 170. The depressed roadway segment of the corridor in downtown Los Angeles has a narrow ROW with several tightly clustered overpasses. High retaining walls with adjacent frontage roads and dense commercial land uses are typical (figure 12). A summary of the geometric characteristics for the corridor is given in table 2.

Automated Highway System Design Concepts

There are basically three ways of integrating automated highway systems into existing freeway infrastructures; either at-grade, above-grade, or below-grade. The **at-grade** concept consists of at least one of the existing roadway lanes being converted, or

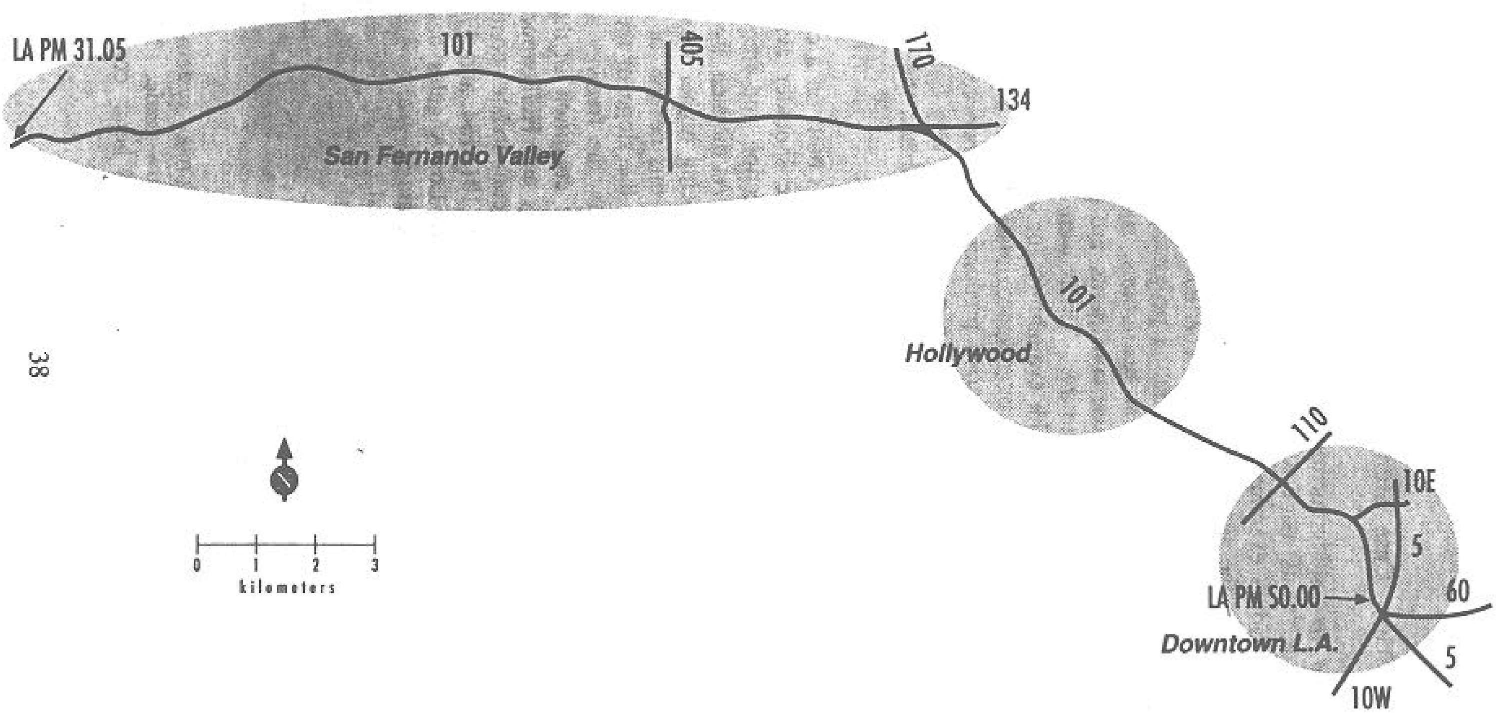


Figure 12. Urban Case Study Corridor: U.S. 101 (LA PM S0.00 - LA PM 31.05)

TABLE 2.

Summary Of Physical Features For Selected Urban Case Study Corridor (U.S. Route 101)

Characteristic	Statistics
Overpass Density (number of overpasses per kilometer)	
Vehicle	0.73
Pedestrian	0.06
Railroad	0.02
Restrictions to Lateral Roadway Expansion (percentage of corridor length for each direction)	
Sound Walls	8.5/7.3
Retaining Walls	8.2/8.8
Frontage Roads	0.6/2.5
Land Uses	7.7/1.2
Tunnels	None
Presence of HOV Lanes	None
Availability of Median Space For Additional Lanes (percentage of corridor length)	
One lane	36.1
Two lanes	7.5
Three lanes	6.7
Existing Number of Lanes (percentage of corridor length)	
Four lanes	88.1
Five lanes	9.3

Terrain type for the corridor consisted of almost the entire range of possibilities, from very flat to hilly with steep slopes.

additional lanes constructed at-grade for automated use. The **above-grade** concept consists of automated lanes built on an elevated structure above either existing median space or creating new space by expanding the ROW. The **below-grade** concept refers to the situation where automated highways are built under existing roadways either as an underground tunnel or a lower deck of a bridge. Design options under these alternative concepts are presented in this section.

At-grade Deployment Concept

Two design approaches are plausible with this concept. One approach is the "shared geometric configuration" which allows vehicles to merge from manual (non-automated) lanes first to a transition lane and then onto the automated lane(s). The second approach is the "dedicated geometric configuration" in which separate access and egress facilities for the automated lane(s) are provided directly from local streets, thereby not requiring automated vehicles to utilize the non-automated portion of the freeway.

In the former case, a properly equipped vehicle enters a transition lane under manual operation, with the automated system assuming control of the vehicle after a "check-in" procedure, followed by the vehicle entering the automated lane when merging space is available. For vehicles to transition from automated to manual mode, the reverse of this process would occur via a "check-out" procedure occurring in the transition lane. Strategically placed concrete barriers between the transition lane and the adjacent manual lane and between the transition lane and the adjacent automated lane are proposed in order to segregate automated from non-automated vehicles to the extent possible for safety reasons.

It is suggested that entry points, i.e. automated facility check-in points, be located approximately 3.5 km apart. Exit points (check-out) would need to be located approximately 2 km following each entry point in order to allow for adequate space in which to perform entry and exit maneuvers to and from the automated lane. Vehicles wishing to exit the freeway must use an exit point far enough upstream of the desired off-ramp to allow sufficient distance in which to weave through traffic to the right lane prior to reaching the off-ramp, which will vary with traffic conditions. Entry/exit zones (check-in to check-out), areas of approximately 2 km in length in which automated lane entry and exit maneuvers take place between the automated and transition lanes, would be spaced approximately 1.5 km apart to allow for the movement of vehicles between manual and transition lanes. Within these 1.5 km weaving zones, there would be no barrier between the transition lane and the adjacent manual lane and no openings in the barrier between the transition lane and the automated lane (figure 13).

To allow for vehicles to transition between manual and automated modes, strategically positioned gates, or openings, in the barriers between the transition and automated lanes would be necessary. It is suggested that gates be offset in such as way so that at

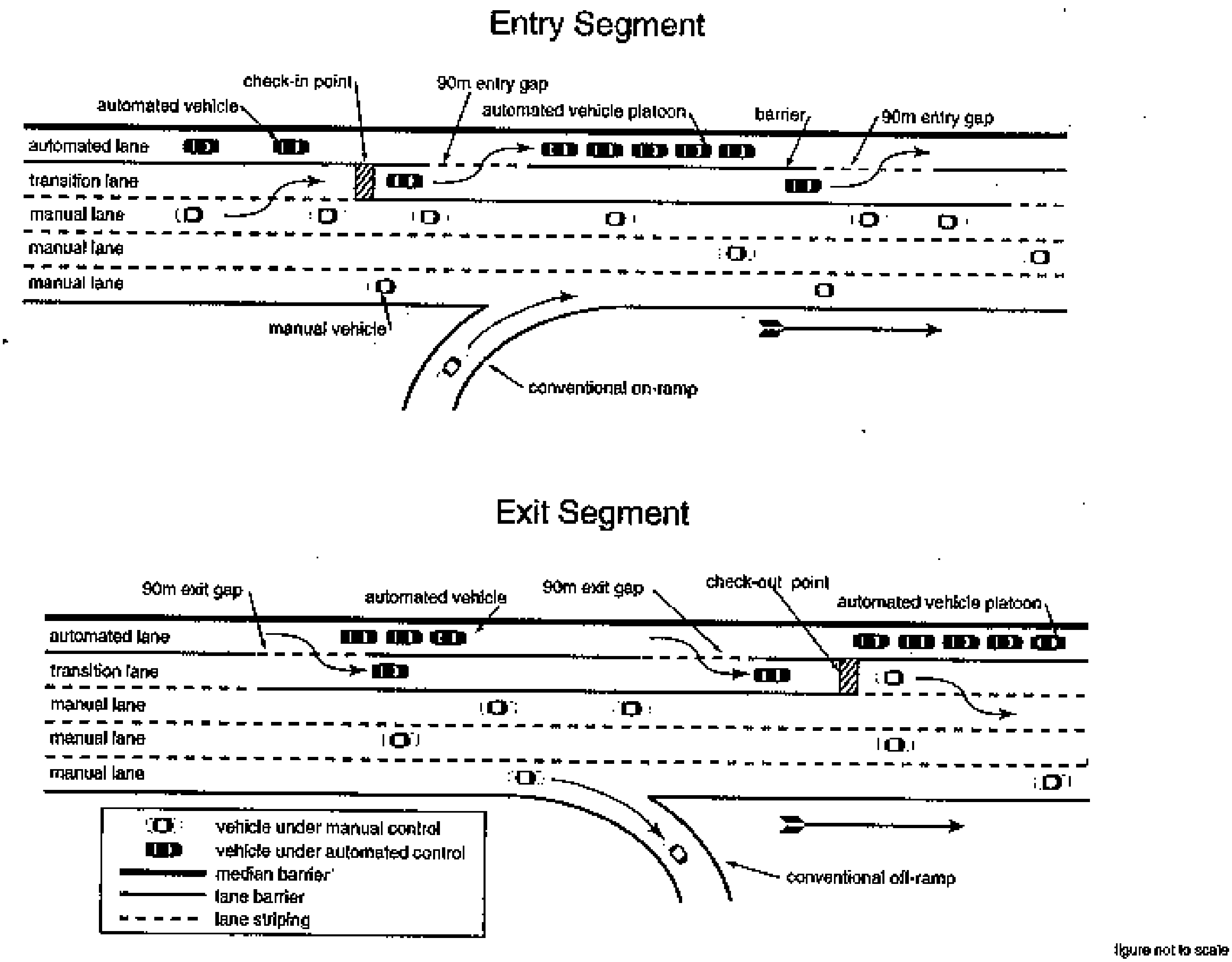


Figure 13. Entry/Exit Zone: Shared Space Concept

all points along the automated facility at least one barrier separates the automated and non-automated lanes. Under this option, vehicles utilizing the automated facility enter and exit the highway through existing on- and off-ramps, thereby minimizing construction costs and environmental impacts.

An alternative approach assumes an automated lane which is completely separated from the manual lanes by a continuous barrier. The use of a continuous barrier would provide improved safety and operation through the physical separation of manual and automated vehicles. However, since vehicles would not be able to gain access to the automated facility from the manual lanes, this option would require the provision of dedicated access and egress facilities to and from the automated facility. Such facilities could consist of ramp flyovers constructed over the manual lanes and connected to an elevated segment of the automated facility or ramps connected to the automated facility from existing freeway overpasses. The use of exclusive entry and exit facilities would limit access and egress opportunities as compared with existing on- and off-ramps, may require the acquisition of additional ROW for the construction of such facilities, and may impact traffic on local streets near those entry/exit facilities.

For the first option, in which a transition lane is used, a minimum of four lanes in each direction of travel is required, assuming one automated lane, one transition lane, and two manual lanes. It is implicitly assumed that the market penetration of automated vehicles is consistent with having taken away two lanes from manual use. A minimum of two manual lanes is necessary, to adequately accommodate AHS entry/exit maneuvers, weaving movements between the manual lanes and transition lane, on- and off-ramp movements, and to allow for passing in the manual lanes to accommodate slower moving manual traffic. For the second option, since a transition lane is not used, a minimum of three lanes in each direction of travel is required. For highway segments with less than four lanes in each direction, the implementation of the first option would require the lateral expansion of the roadway. Depending upon the availability of usable space within the existing ROW and the severity of restrictions to lateral expansion beyond the ROW, the implementation of the first option may be costly and may displace existing land uses and other physical obstacles. The implementation of the second option could require the construction of costly entry/exit facilities, possibly necessitating the displacement of existing land uses and other physical obstacles as well.

Due to the spatial requirements of lane barriers, on many urban freeways lateral expansion of roadways would be necessary in order to accommodate the shared automated/manual infrastructure type. In each direction of travel, lane barriers and barrier shoulders would require the traveled way to be widened by 2.1 meters (figure 14). The need for lateral expansion of the roadway beyond the outside shoulder is dependent upon the availability of median space and lane widths. The standard minimum median width for freeways is typically considered to be 1.2 meters, comprised of a concrete median barrier (0.6 meters wide at the base) and 0.3 meters

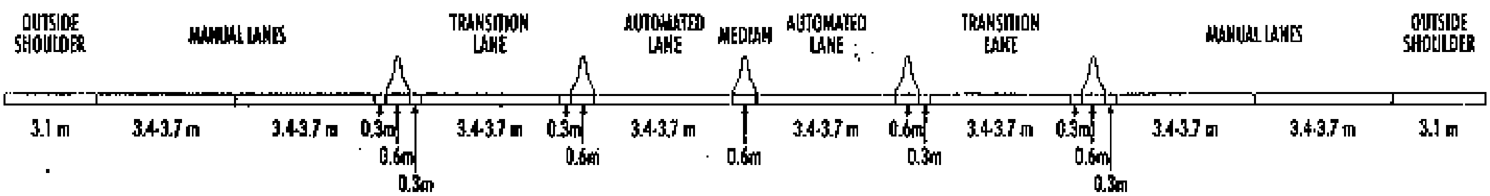


Figure 14. Typical Cross-Section of At-Grade Shared Configuration for AHS

inside shoulders on each side of the barrier. It is proposed that inside shoulders would not be necessary along median barriers in an automated system since vehicles in the median lanes would be under automated control at all times. Many freeway medians are wider than 1.2 meters and in many cases are significantly wider. Upon conversion of a freeway to the shared automated/manual infrastructure type, it is recommended that, to the extent possible after allowing for needed center supports for overpasses, available median space be converted to roadway in order to minimize the extent of lateral expansion beyond the outside shoulder.

The standard lane width for freeways designed to accommodate heavy duty vehicles is 3.7 meters. However, the use of 3.4 meter lanes is a common practice on freeways which permit heavy duty vehicles, especially along freeway segments in which lanes have been added and ROW availability is extremely limited. In order to minimize the extent of lateral expansion necessary to accommodate the shared automated/manual infrastructure type, it is recommended that all lanes be 3.4 meters in width. The conversion of 3.7 meter lanes to 3.4 meter lanes would minimize the extent of lateral expansion necessary. For example, if a 10 lane freeway with 3.7 meter lanes and a median width of 1.8 meters is converted to a 10 lane shared automated/manual infrastructure type, by reducing the lane widths to 3.4 meters and reducing the median width to 0.6 meter, no lateral expansion of the roadway beyond the outside shoulders would be necessary. Existing outside shoulder widths should be maintained, and, in some cases, widened to reflect current design standards. Outside shoulder widths should not be reduced in order to accommodate the spatial requirements of an automated highway system except in rare cases in which the outside shoulders are wider than current standards require. Where lateral expansion is required beyond the outside shoulders, outside shoulders should be converted to freeway lanes and reconstructed beyond the right-most lane. On freeways with 3.7 meter lanes and median widths of at least 4.9 meters, available median space is sufficient to accommodate the spatial requirements of the shared at-grade system without requiring the reduction of lane widths to 3.4 meters. However, by reducing lane widths to 3.4 meters, the cost of the system would be reduced since the amount of median space converted to freeway lanes would be minimized.

<u>Above-grade Deployment Concept</u>

Above-grade automated highway facilities could be built above existing roadways through the use of elevated structures, utilizing existing rights-of-way where possible. When cost, seismic safety hazards, and visual impacts are considered, the use of such facilities may be deemed appropriate where at-grade facilities are not feasible. Structural supports for above-grade facilities could be located within the median area, if adequate space is available. In areas where the existing median width is not sufficient to accommodate these structures, the median area could be widened by taking space away from the traveled way, through lateral expansion of the roadway, utilizing space beyond the outside shoulders, or via a combination of these options. For a two-lane elevated automated facility, it may be necessary to provide an emergency lane adjacent to each automated lane where emergency vehicles could gain access to incidents within the automated lanes (figure 15). Alternatively, a single emergency lane for the whole facility would reduce the above-grade structure's spatial requirements. Moveable barriers could be used, or alternatively openings in the barriers, between the automated lanes and the emergency lane, enabling access to any portion of the automated facility by emergency vehicles. Since vehicles would not be able to gain access to the automated facility from the manual lanes, this option would require dedicated facilities for access and egress to and from the automated facility. Such facilities could consist of ramp flyovers constructed over the manual lanes and connected to the elevated automated facility or via ramps connected to the middle of existing vehicle overpasses with connecting ramps going to and from the AHS lane located in the middle of the freeway.

This dedicated entry/exit concept would provide improved safety and operation through the physical separation of manual and automated vehicles. It introduces, however, many issues including the possible need for acquiring additional ROW, structural engineering challenges in designing flyover structures, and potential traffic impacts on local streets near entry/exit facilities. The cost premium in addressing these issues may be substantial and needs careful consideration.

<u>Below-grade Deployment Concept</u>

Below-grade automated facilities would consist of underground tunnels and underpasses. Although tunnel construction is costly at present, some experts believe that the cost of tunnel construction may decrease dramatically as tunneling technology improves. Tunnel construction may require the relocation of underground utilities and the provision of sufficient ventilation to prevent dangerous accumulations of vehicle emissions. Below-grade facilities are considered to be feasible only for short distances and in areas where the existing roadway is not presently depressed.

Evaluation of AHS Design Concepts

To assess the implementation potential of the above concepts with respect to existing freeway infrastructure characteristics, these concepts were further evaluated by examining the physical features of the selected corridor. A hierarchy of deployment concepts was established based on evaluation criteria. The urban case study corridor was subsequently divided into 10 segments possessing approximately uniform physical characteristics. The feasibility of each AHS design concept was then evaluated for each segment based on the established hierarchy of deployment concepts.

[Insert figure 15 here]

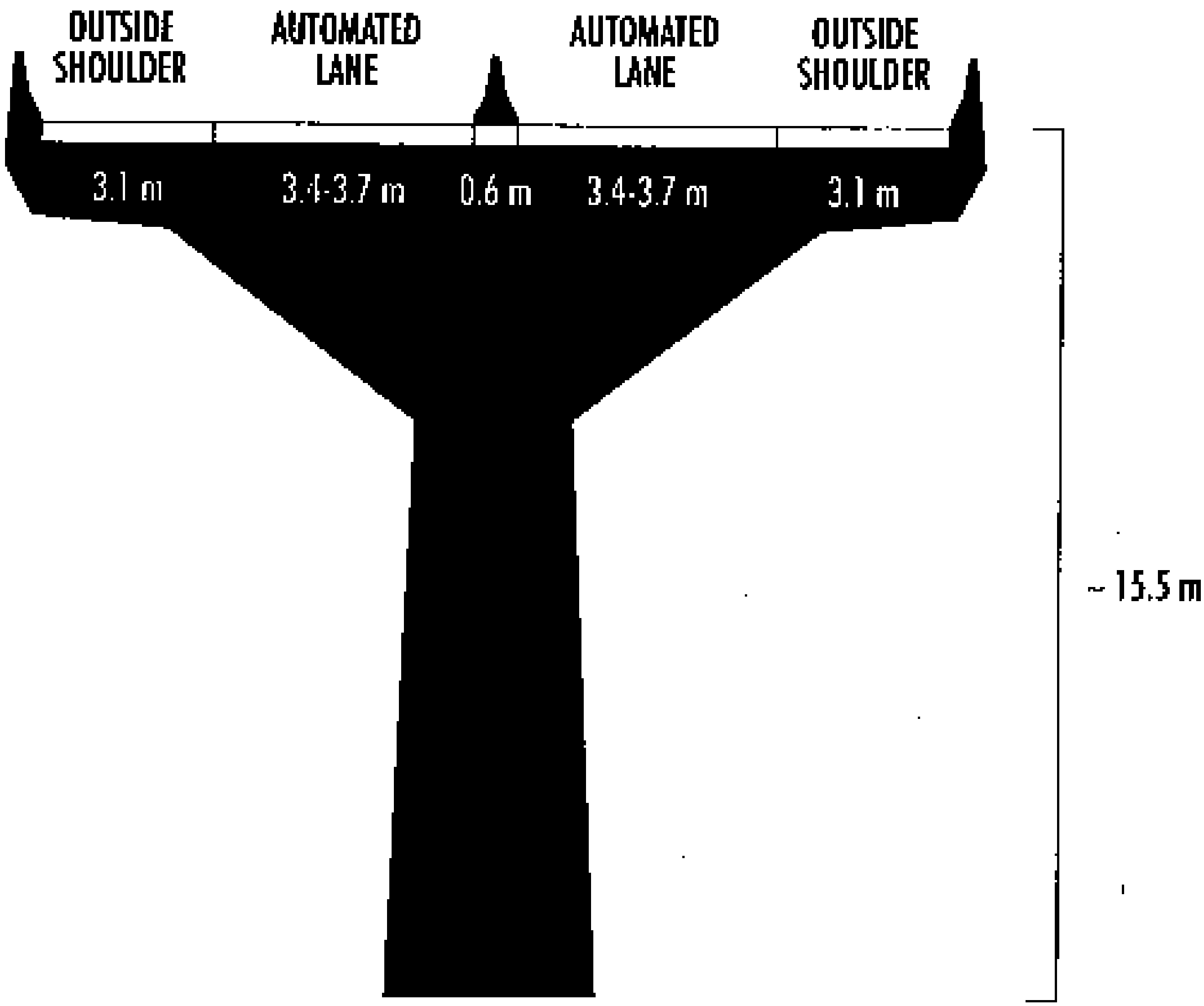


Figure 15. Typical Cross-Section of Dedicated Elevated Configuration for AHS

Evaluation Criteria

The evaluation criteria for the deployment concepts were established based on concerns pertaining to the implementation of AHS facilities and are listed as follows:

- rights-of-way-Minimize the acquisition of real estate for additional ROW and maximize the use of the existing rights-of-way.
- environmental-Minimize the visual, air quality, and noise impacts of the AHS facility, and maximize the compatibility of the AHS structure with adjacent land uses.
- cost-Minimize the capital and operating costs for AHS construction and maintenance, including modifications of the existing roadway infrastructure.
- natural hazards-Minimize seismic hazard risks.
- construction impact-Minimize the interruption of traffic during construction.

Design Criteria

Based on the above evaluation criteria, specific design criteria were formulated. First, it was determined that the implementation of an automated facility through the conversion of existing traffic lanes, or the at-grade lane conversion concept, should be given priority over all other design options. The at-grade lane conversion concept is the least costly alternative to implement since ROW acquisition is either unnecessary or extremely minimal and the extent of modifications to the existing infrastructure is less extensive than the other alternatives, does not introduce any new seismic safety hazards, and does not result in any significant visual and noise impacts.

Second, at-grade lateral expansion of roadways should utilize median areas to the extent possible. The use of available median space to accommodate lateral expansion is desirable since this land is already a part of the existing ROW, thereby minimizing the need for ROW acquisition or avoiding ROW acquisition altogether. Expanding the rights-of-way of existing freeway facilities in urbanized areas, especially areas containing residential development, can be extremely costly and is often met with strong opposition from landowners and residents. Due to these issues, politicians would understandably be hesitant to endorse a proposal which requires extensive displacement of existing land uses, particularly when public opposition is likely.

Third, the use of elevated structures should be avoided to the extent possible. Elevated structures are extremely costly to construct, require the use of costly exclusive entry/exit facilities, introduce new seismic safety hazards, and results in potential significant visual and noise impacts. However, elevated facilities may be the most desirable alternative for freeway segments which do not contain adequate ROW to accommodate an at-grade facility and where restrictions to lateral expansion of the roadway make it infeasible to do so. In such cases, the cost of at-grade lateral expansion may be significantly higher and less acceptable to the public than the use of an elevated facility.

Fourth, the use of tunnels should be avoided to the extent possible and should only be considered for relatively short distances. Like elevated structures, tunnels are extremely costly to construct and introduce new seismic safety hazards. In addition, tunnel construction may require the relocation of underground utilities, typically an extremely costly and cumbersome undertaking. The length of tunnels would need to be limited and/or sufficient ventilation mechanisms would be required in order to avoid the accumulation of unsafe levels of vehicle emissions within tunnels. While tunnel construction is extremely expensive at present, some experts believe that the cost of tunnel construction may decrease dramatically as tunneling technology improves, possibly enabling extensive use of tunnels in constructing automated facilities. These design criteria were used in establishing the hierarchy of implementation options discussed below.

Hierarchy of Implementation Options

Each of the automated highway deployment concepts was qualitatively evaluated in terms of the above criteria. Based on this evaluation, the following hierarchy of implementation options, from the easiest and most desirable to most difficult and least desirable to build, was established:

- At-Grade - lane conversion: Existing lanes are used for automated, transition, and manual lanes. Minimal lateral expansion of the roadway is necessary.
- At-Grade - median: Available space within the median is used to accommodate lateral expansion of the roadway in order to provide a sufficient number of lanes for an at-grade automated facility.
- At-Grade - median and shoulder: A combination of available space within the median and beyond the outside shoulders is used to accommodate lateral expansion of the roadway in order to provide a sufficient number of lanes for an at-grade automated facility.
- At-Grade - shoulders: Available space beyond the outside shoulders is used to accommodate lateral expansion of the roadway in order to provide a sufficient number of lanes for an at-grade automated facility.
- Above-Grade - median: Available space within the median is used to accommodate the structural supports for an elevated automated facility.
- Above-Grade - shoulders: If available median space is insufficient to accommodate the structural supports for an elevated automated facility, available space beyond the outside shoulders is used to expand the roadway, thereby freeing up the required space within a widened median area.
- Below-Grade - tunnel: An automated facility constructed below the existing grade level of the roadway.

Implementation Potential for Each Deployment Concept

Based on the general uniformity of various physical characteristics of the urban case study corridor, the corridor was divided into 10 segments (figure 16). For each segment, the feasibility of each of the seven design options listed above was evaluated based on the physical characteristics of the segment. Physical characteristics considered in rating the various design options were:

- restrictions to lateral expansion (i.e., land uses, retaining walls, frontage roads),
- median width
- segment length
- number of lanes (under the assumption that a minimum of four lanes in each direction would be required to accommodate lane conversion)
- presence of underpasses (under the assumption that underpasses would present difficulties in constructing above-grade facilities since elevated structure supports would have to "punch" through the roadway to the ground below)

A detailed description of the 10 segments is contained in appendix 8.

<u>Selected Concepts for Urban Case Study Corridor</u>

Based on the physical and geometric characteristics of each segment of the urban case study corridor and the hierarchy of implementation options outlined above, design concepts for each segment were formulated. Due to the varying characteristics present throughout the length of the corridor, the selected design concepts are not uniform throughout the corridor. A matrix containing the rating of automated highway design concepts by segment and a detailed interpretation of these ratings can be found in appendix 9.

The lane conversion concept appears to have the least difficulty for AHS implementation for approximately 83 percent of the urban case study corridor's length (figure 17). With this concept, lane barriers could be used to separate manual and automated vehicles with openings for entry and exit. Existing on- and off-ramps are utilized, minimizing construction costs and environmental impacts. Despite these features, this concept poses several issues to resolve, namely:

- manually driven vehicles are not completely prevented from entering the automated portion of the roadway
- physical lane barriers could present a safety hazard to vehicles changing lanes through barrier openings
- capacity of the manual lanes would be reduced due to vehicles weaving through these lanes to access the automated lane
- capacity of the automated lane could be significantly reduced by congestion in the manual lanes, as such congestion would affect access to and egress from the

[Insert figure 16 here]

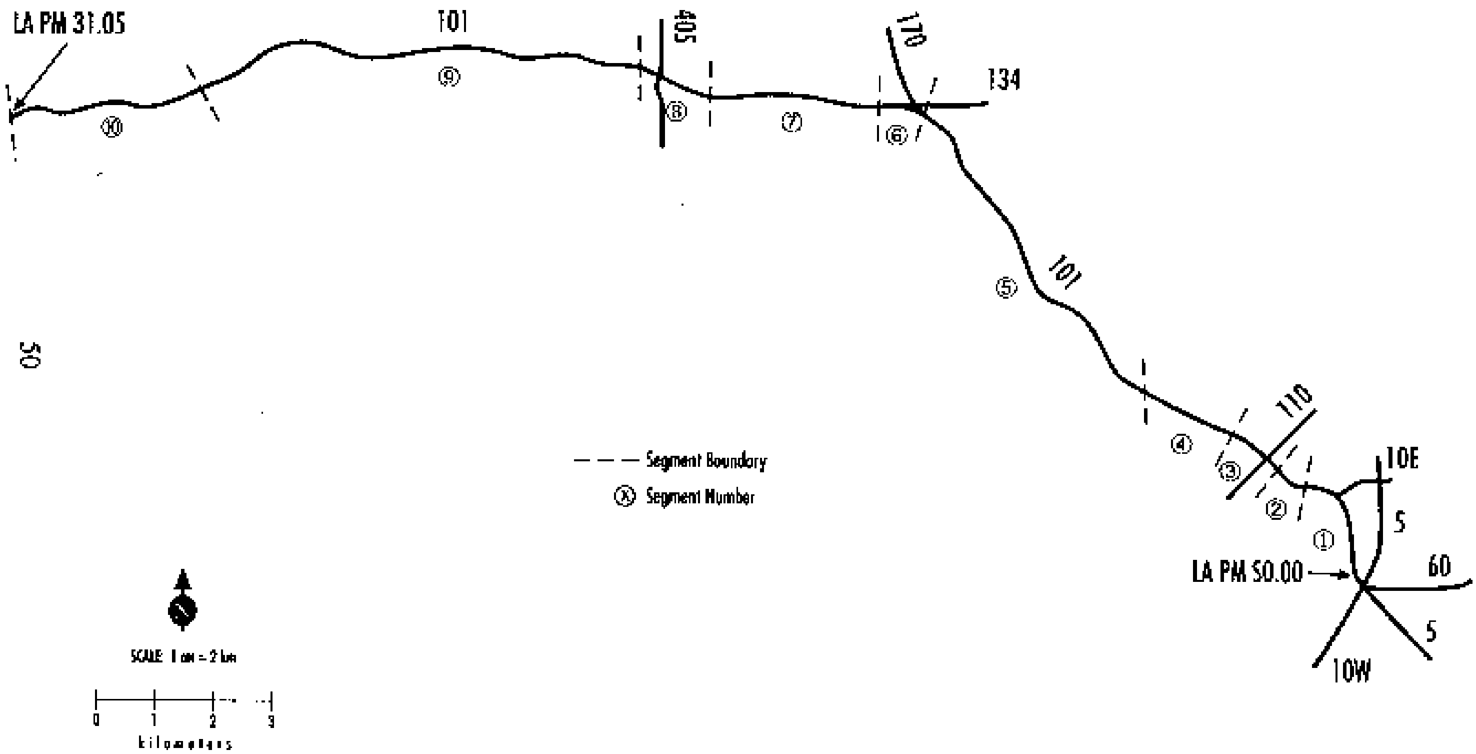
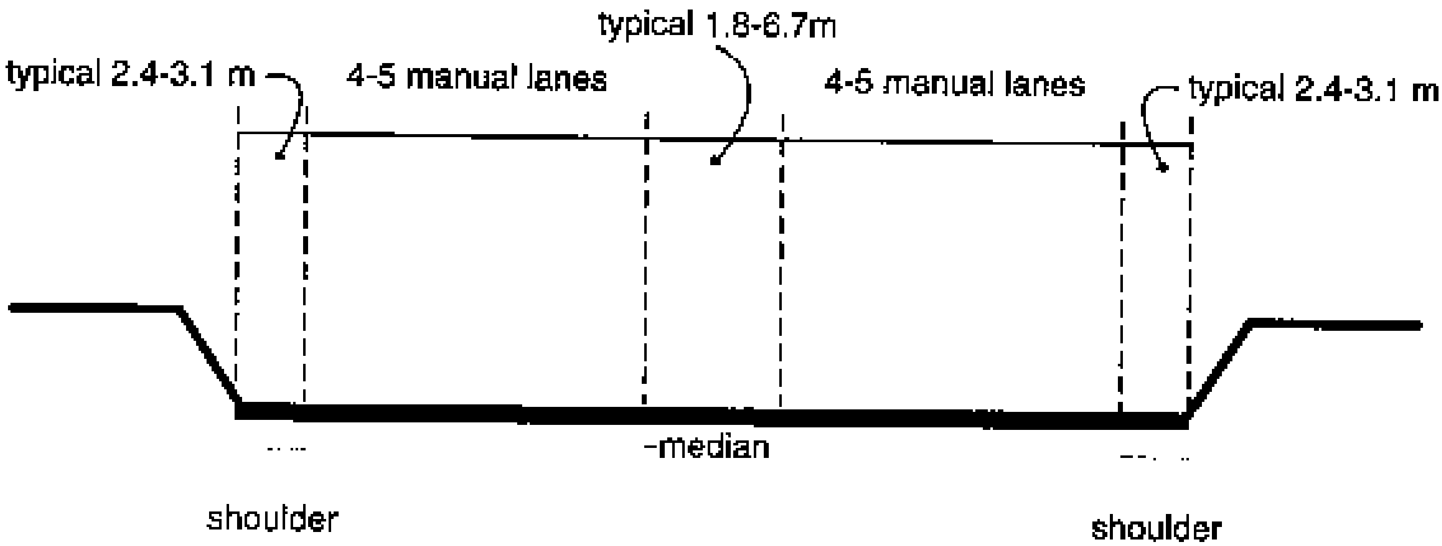
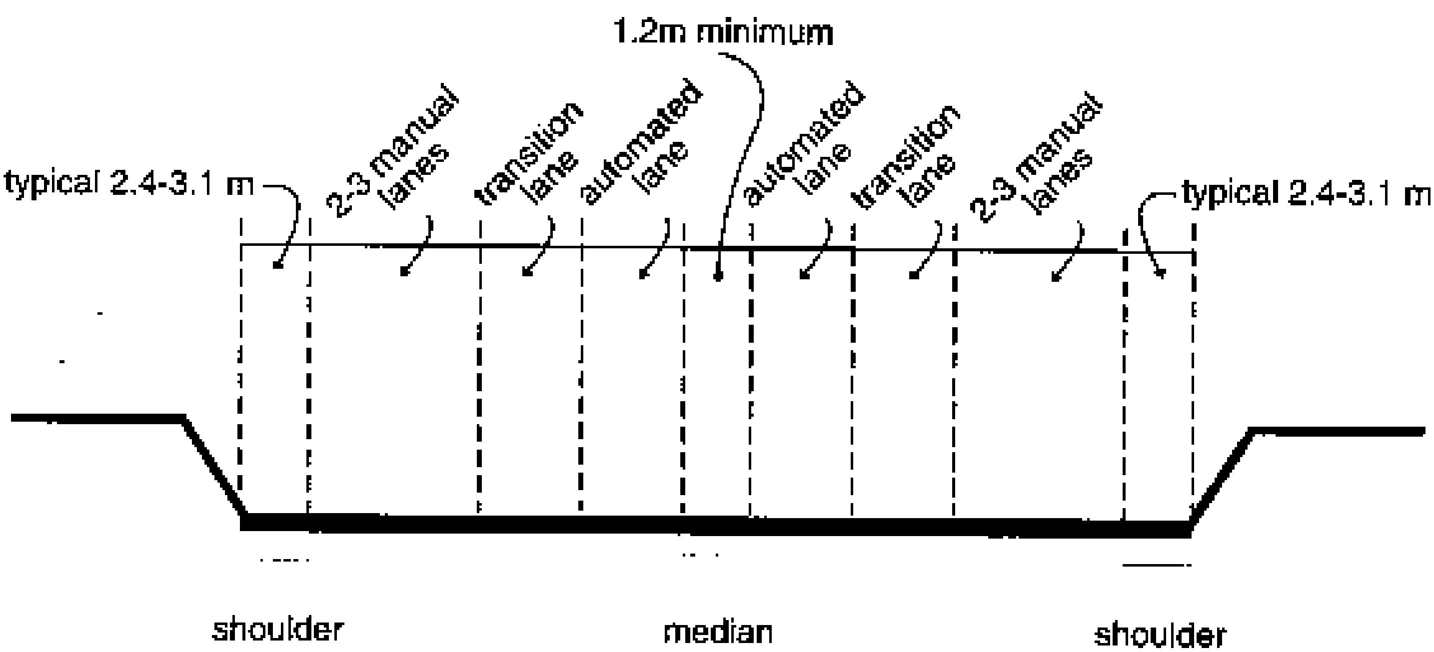


Figure 16. Ten Segments of U.S. Route 101



(a) Existing Roadway Configuration



(b) Lane Conversion Option

figure not to scale

Figure 17. Typical Lane Conversion Scenario

automated lanes.

Some of these concerns can be avoided when the automated and manual lanes are within the same ROW but are physically separated. This modified configuration would use a continuous barrier separating automated from manual lanes and would utilize dedicated entry/exit facilities, thereby not requiring the use of a transition lane. Such a system could be more costly to construct and require a greater amount of real estate.

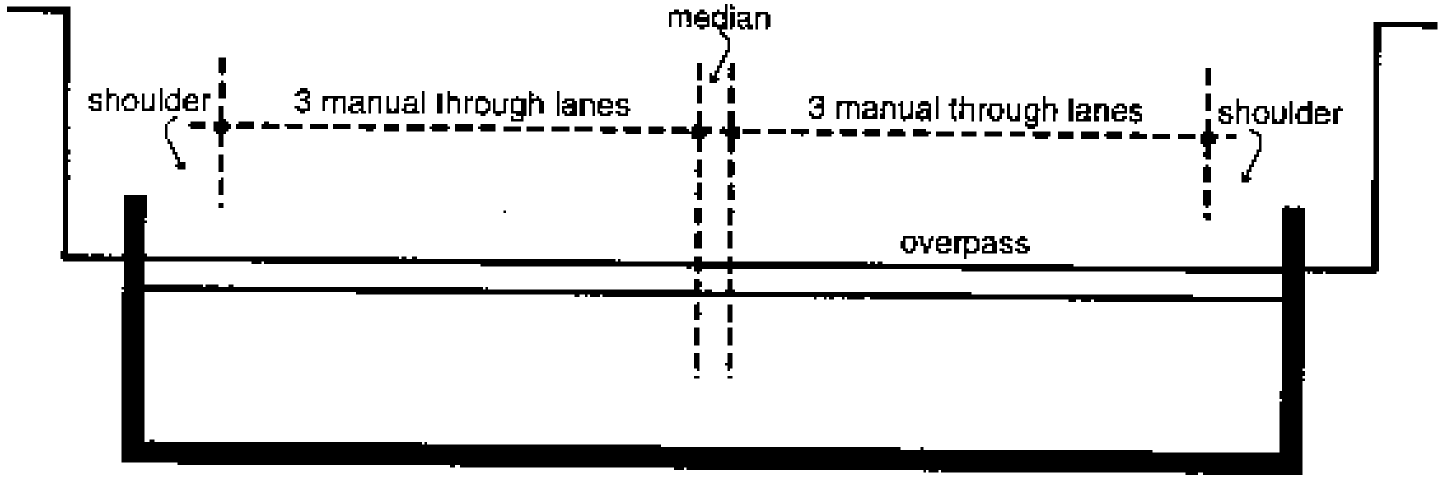
Splits and merges at freeway interchanges become more challenging with automated lanes. This situation occurs along Route 101 where it intersects two other freeways (Routes 134 and 170). Significant roadway modifications may be required to allow a continuous automated lane while providing all necessary options to both the automated and manual vehicles, since this interchange contains left lane splits and merges. Tunnels or flyovers can be introduced to provide continuous automated travel on the roadway when there is a split or merge in the left lane(s). Such reconfiguration of freeway interchanges can be costly, especially if additional ROW must be acquired. Tunnel construction may require the relocation of underground utilities and lengthy tunnels require sufficient ventilation to prevent dangerous accumulations of vehicle emissions.

Where the portion of the corridor passes through the dense downtown area of Los Angeles, ROW availability is extremely limited. Since the existing four lanes are needed to facilitate manual vehicle traffic and adding additional lanes is not feasible, an above-grade structure is a possible option (figure 18). In this concept, automated and manual vehicles are physically separated. As the automated lane rises above the existing roadway, issues such as cost, seismic safety, and visual impacts become important considerations. This is not, however, unique to automated highway systems, as these same issues were present for all elevated highway structures.

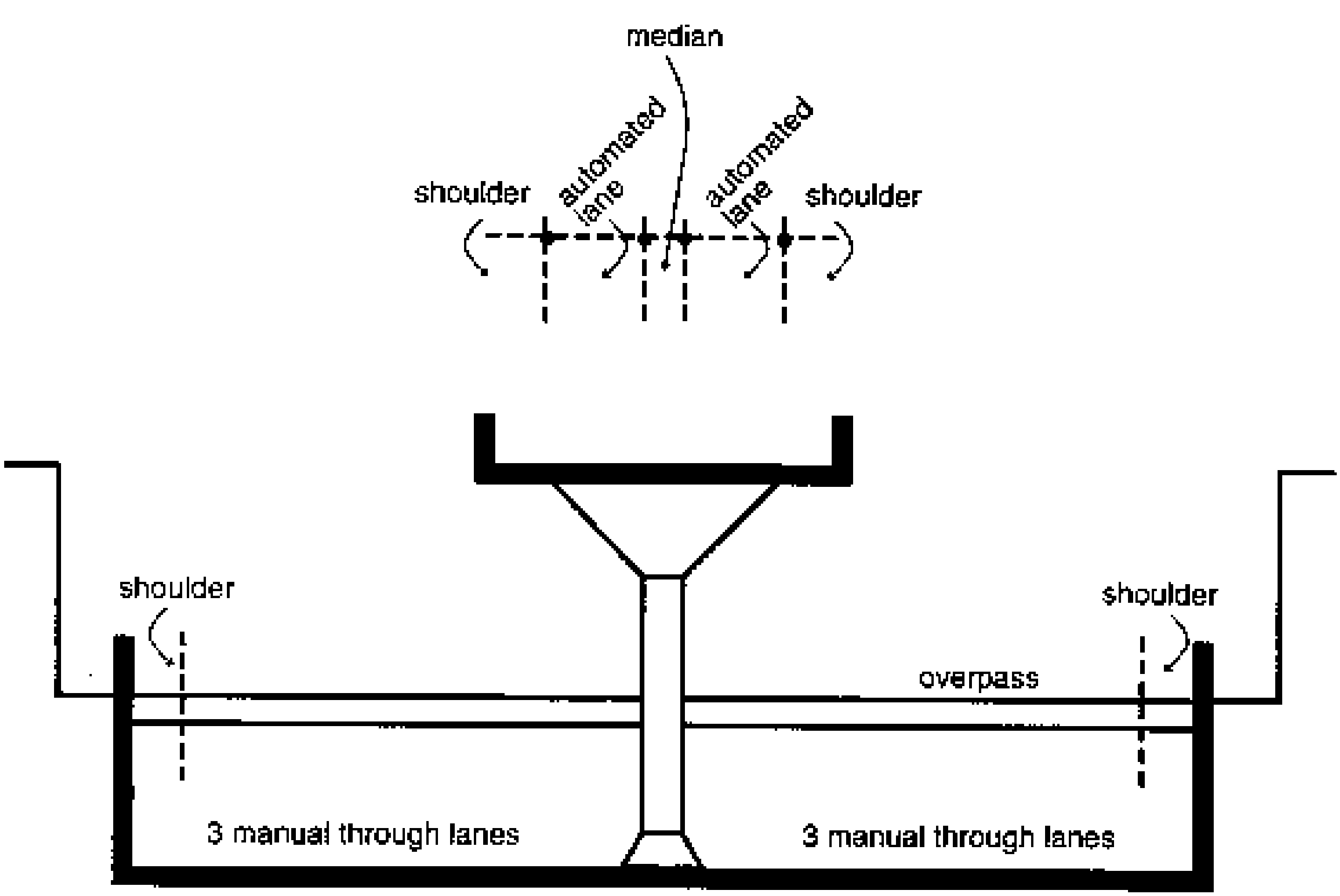
Dedicated access and egress facilities, consisting of flyovers or ramps from existing overpasses, can provide separate entry and exit facilities for grade separated roadways (figure 19). Such exclusive automated entry and exit facilities would probably be spaced further apart than conventional on and off-ramps. This concept would provide improved safety and operation through the physical separation of manual and automated vehicles. These exclusive entry and exit facilities, however, would limit access and egress opportunities since they are less frequently spaced than conventional on- and off-ramps, may require the acquisition of additional ROW and may impact traffic on local streets near such entry/exit facilities. Because cost is likely to be an important issue, the use of lighter-weight construction materials and methods to reduce the spatial requirements of elevated structures should be investigated relative to the above-grade deployment concepts.

In summary, the recommended design concepts are as follows: at-grade lane

[Insert figure 18 here]



(a) Existing Roadway Configuration



(b) Above-Grade Option Using Median Space to Accommodate Supports

Figure 18., Segment Through Downtown Los Angeles

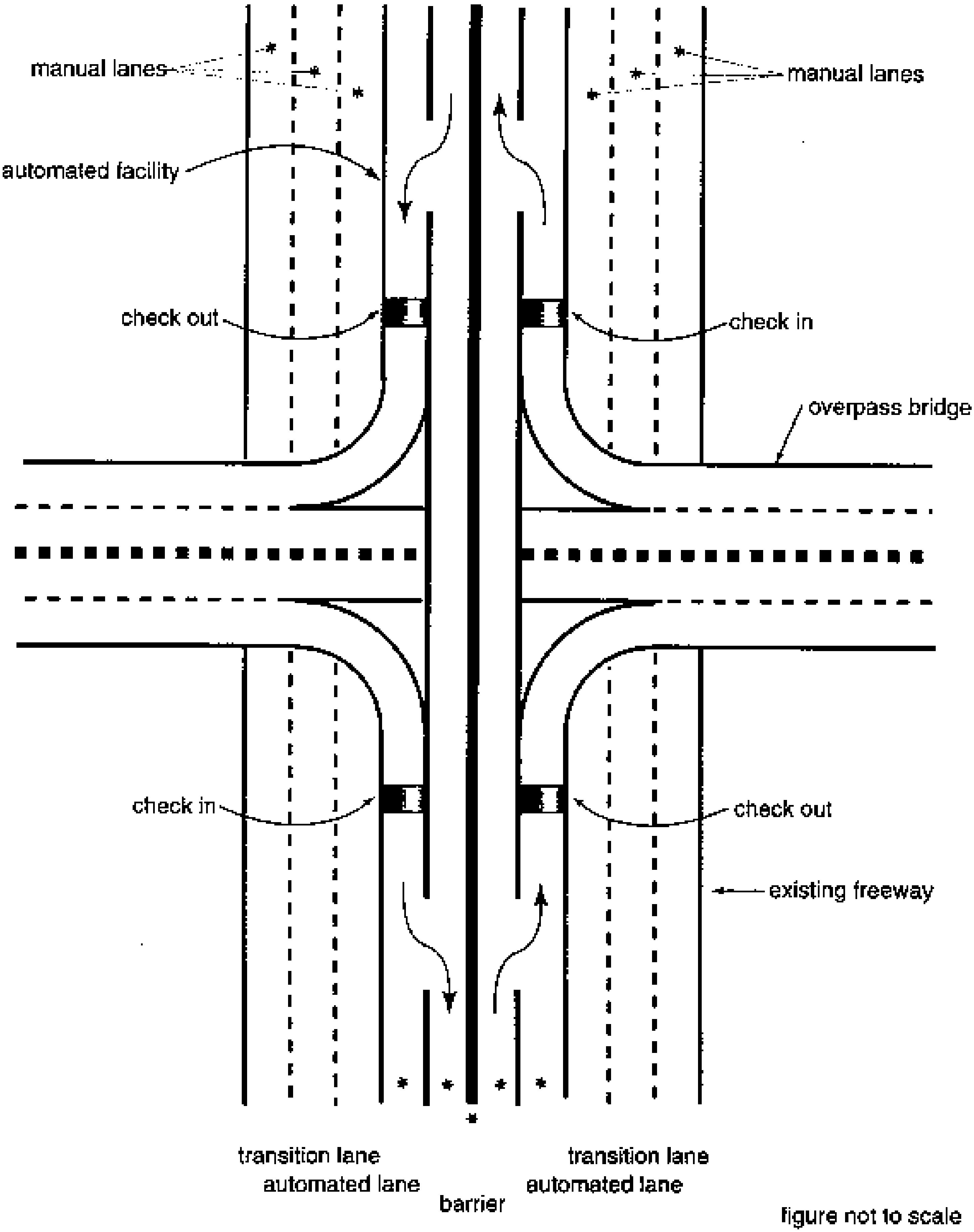


Figure 19. Dedicated Entry & Exit Concept for Elevated AHS

conversion concept (5 segments); at-grade concept with lateral expansion within median space and space beyond the outside shoulders (3 segments); above-grade concept within median space (1 segment); and above-grade concept with lateral expansion within space beyond the outside shoulders and median space (1 segment).

Issues and Risks Associated With AHS Deployment

The specific issues and risks associated with each of the concepts considered above would vary significantly depending on site-specific conditions and thus they must be addressed within the context of the actual deployment location. Implementation of AHS must also consider the trade-offs between the shared and dedicated automated highway system concepts such as entry and exit, cost, safety, traffic operations, and implementation phasing issues. The issues presented in this report are directly related to those AHS deployment concepts that were examined for the selected segment of U.S. Route 101 corridor. The emerging issues identified in the process of evaluating those AHS deployment concepts mostly pertained to the operational features of the shared space concept, design considerations for the above- and below-grade automated facilities, and environmental concerns associated with automated facilities and adjacent land uses.

Operational Features of the Shared Space Concept

The operational features of the shared space concept include the (1) effects of weaving activities on the capacity of manual lanes where lane changes must take place to enter the automated lane through the transition lane, (2) requirements of physical barriers and design solutions for separating automated, transition, and manual lanes, (3) hazards of mixing manual and automated vehicles on the automated lane, and (4) the psychological impact of lane barriers on drivers.

Effects of Weaving Activities on Manual Lane Capacity

As stated earlier, the shared space concept does not provide exclusive entry and exit facilities for automated vehicles. In this concept, vehicles would use existing on- and off-ramps, thereby, requiring vehicles to weave through the manual lanes prior to entering the automated lane via a transition lane and to weave through the manual lanes after exiting the automated lane in order to exit the freeway. The capacity of an automated lane is expected to be significantly greater than the capacity of a manual lane. Therefore, when the automated lane is operating at or near capacity, weaving activities associated with entering and exiting the automated system may result in a significant reduction of the capacity of the manual lanes. When the manual lanes are congested, this may result in under-utilization of the automated lane(s) capacity due to the difficulty involved in weaving through the manual lanes prior to entering the automated system. Lane barriers between manual and automated systems could further amplify these problems, since vehicles would be allowed to maneuver between the transition lane and adjacent manual lane only at points where barrier openings are provided;

this restriction to free lane-to-lane movements could result in further congestion in the manual lanes.

Barrier Requirements Between Manual and Automated Systems

For the shared space concept where the automated facility is located in the left-most lanes, several previously conducted studies indicate that physical lane barriers are necessary to separate the automated lanes from the manual lanes for reasons of safety and operational efficiency.(7) If lane barriers are to be used, an appropriate barrier type must be identified prior to AHS implementation. A candidate barrier design investigated for this study was the Caltrans' Concrete Barrier - Type 50 which is representative of the standard concrete median barrier used on freeways with narrow medians. This barrier is 0.61 meters wide at the base contouring to a width of 0.15 meters at the top with a total height of 0.81 meters. This barrier requires little maintenance and is able to prevent major accidents. With this barrier, it has been found that most vehicles that collided with the barrier were redirected by the "safety shape" with no damage and were able to drive away. Furthermore, this is the cleanest barrier in terms of design, with no projections to collect debris.(8) Because of the aforementioned attributes of this barrier type, it is believed that a barrier of similar design would be appropriate for the AHS shared space configuration. Due to the space requirements of this barrier type, in addition to any buffer space provided between barriers and lane boundaries, some degree of lateral expansion of roadways would likely be necessary to accommodate these barriers.

The other issue concerning barriers is the design of the barrier end treatment. Isolated freestanding ends of lane barriers following openings could present a safety hazard to approaching traffic and therefore must be shielded from impacts. This may be done by placing an appropriate crash cushion at the approach end of the barrier. Warning pylons or other devices placed in front of crash cushions can be used to alert drivers of the approaching hazard. Reflector units or electric lights along the top of barriers can be used to provide enhanced delineation at night and during adverse weather conditions. While such warning devices are not needed for vehicles under automated control, it would be needed by those vehicles who fail automated lane check-in and must proceed until check-out under manual control to return to the manual lanes. Despite the use of crash cushions, isolated free standing ends of barriers would remain a hazard. Barrier openings must be of sufficient length to provide ample opportunities for lane change maneuvers under all traffic conditions. Furthermore, openings in the two adjacent barriers separating the automated, transition, and left-most manual lanes should not be adjacent to one another to ensure that the automated lane(s) are protected from accident debris by at least one barrier to the greatest extent possible.(8)

Vehicle Segregation Within Shared Automated/Manual Facilities

In order to allow vehicles to shift among the manual, transition, and automated lanes in the shared facility, strategically positioned openings in the lane barriers would be necessary. Due to these barrier openings, it would be impossible to prevent manually driven vehicles from entering those portions of the roadway designated exclusively for vehicles under automated control. Drivers under the influence of drugs or alcohol may inadvertently enter the automated facility. Thrill-seekers and trouble-makers may purposely enter the automated facility under manual control. Debris from accidents in the manual lanes could potentially reach automated portions of the roadway, depending upon the location of openings in adjacent lane barriers and the angle of approach of the debris. Under this infrastructure type, there are no apparent design options available to ensure that manually operated vehicles would be unable to enter automated portions of the roadway. Due to the expected significant increases in lane capacities and vehicle speeds attainable under automated control, the effects of unauthorized vehicles entering the automated facility could be severe.

Psychological Impacts of Barriers

Along stretches of the automated and transition lanes, barriers would be located along both sides of these lanes. In the automated lane, since vehicles will be under automatic control at all times the barriers on both sides of the lane would not necessarily pose a safety hazard. However, these barriers may give motorists a feeling of psychological confinement. In the transition lane, vehicles which fail check-in would have to manually drive through a short section of roadway with barriers on both sides prior to returning to the manual lane. If transition lanes are 3.7 meters in width, the standard freeway lane width, it may or may not be necessary to provide buffer space between the barriers and the lane boundary since 3.7 meter lanes provide ample space for even the largest passenger vehicles. However, since drivers are unaccustomed to driving through such confined spaces at freeway speeds they may be uncomfortable if required to do so. If heavy duty trucks or buses are permitted to use the automated system, the need for buffer space in areas where vehicles are under manual control would become more apparent due to the wider girth of these vehicles. A narrow buffer, e.g. a third of a meter, could be used to mitigate such psychological impacts of driving under manual control between physical barriers.

<u>Design Requirements for Above- and Below-Grade Automated Facilities</u>

The design requirements for above- and below-grade automated facilities include: (1) the structural engineering of elevated structures, (2) locations of exclusive entry and exit facilities for automated systems, and (3) accommodation of manual lane splits and merges for automated facilities.

Engineering of Elevated Structures

In locations where at-grade AHS facilities were deemed infeasible, elevated structures were considered. In choosing an appropriate elevated structure type for an above-grade automated facility, trade-offs between alternative design concepts, including construction materials, should be assessed. Cost, visual impacts, and seismic safety are the major concerns associated with elevated structures. Considering present construction technologies, one of the possible options for the construction of an above-grade automated facility is a precast high-strength concrete structure as used on the Harbor Freeway Transitway (Interstate 110) elevated structure in Los Angeles. Further advancements in freeway material such as high strength concrete will likely enable the design of elevated structures with smaller structural members than are used today. Advancement in construction methods will also enable assembly of such structures with less time and manpower. Although the design of elevated structures would incorporate the most up-to-date of California State earthquake codes, any elevated structure would pose a potential seismic risk. Technological advances in high-strength light-weight plastic materials should enable designers to reduce costs and lessen the visual and seismic impacts of elevated roadway structures by the time automated highway systems are deployed on a wide scale.

Exclusive Entry and Exit Facilities for Elevated AHS

Exclusive entry and exit facilities for elevated automated highway systems could consist of flyover ramps built over existing roadways or ramps connected to existing vehicle overpasses. On-going research in other activities on the Precursor Systems Analyses program suggests that, because of operational, cost, and space requirements of such facilities, access and egress opportunities exclusively designated for an elevated automated highway system should be provided further apart than is typical on conventional freeways. The design of appropriate structures for the construction of extensive ramps is an important issue. Elevated entry/exit ramps would also represent a seismic safety hazard. Technological advancements in light-weight high-strength concrete, steel, and plastic materials should help future designers to develop safe, aesthetically pleasing structures at a lower cost than is possible today.

Accommodation of Manual Lane Splits and Merges for Automated Facilities

Lane splits and merges located along portions of roadways proposed for automated travel would require special treatment in many instances to allow for continuous automated travel while maintaining the existing split and merge options for manual traffic. For example, many difficulties could arise as a result of the conversion of freeway median space for automated use. Left lane on- and off-ramps could no longer be utilized by manual traffic. Left lane freeway-to-freeway splits would force automated vehicles to change freeways and would not permit manual vehicles to change freeways. Similar difficulties would arise due to left lane freeway-to-freeway merges. Significant roadway modifications may be required to allow continuous automated travel while providing all necessary options for both automated and manual vehicles in these situations. Tunnels or flyovers can be constructed. Despite the availability of options to remedy many of these problems, reconfiguring freeway interchanges can be costly, especially if additional ROW must be acquired. The construction of flyovers and tunnels would introduce new seismic safety hazards. As previously indicated, tunnel construction may require the relocation of underground utilities and lengthy tunnels require sufficient ventilation to prevent dangerous accumulations of vehicle emissions.

Environmental Concerns With Automated Facilities

The environmental concerns with automated facilities are generally associated with: (1) design compatibility with adjacent land use development, (2) land use considerations, and (3) traffic impacts on the local street network.

Design Compatibility With Adjacent Development

When an elevated AHS is built, a new structural element is introduced within the neighborhoods located along the freeway corridor. Even if lighter construction material were used, the visual impact of the elevated AHS structure could be significant, though the significance level may vary depending on its precise location. When the elevated structure is integrated into an area containing many highrise buildings, its visual impact would be less significant than in an area where single-family and low rise multi-family residences and other low rise buildings are located. Therefore, elevated structures in suburban neighborhoods would be far more obtrusive than in high-density areas. Noise and air quality problems could also prevail with an elevated structure. Landscaping and soundwalls are currently used as noise buffers between residential communities and freeways. Specific measures need to be developed for mitigating adverse noise and air quality impacts of AHS in residential neighborhoods.

Land Use Considerations

At-grade automated highway systems can be built either by converting portions of existing roadways for automated use or through the lateral expansion of existing roadways. Where existing roadways are not wide enough to adequately accommodate both automated and manual traffic, lateral expansion of the roadway may be required. A minimum of four lanes in each direction of travel is required to accommodate a shared AHS facility, with one automated lane, one transition lane, and two manual lanes. For highway segments with less than four lanes in each direction, implementation of this design concept would necessitate the lateral expansion of the roadway. In other situations such as for elevated structures where the existing right-of-way does not allow the erection of supporting structural components or the construction of exclusive entry and exit facilities, the acquisition of additional land would be necessary. Lateral expansion of existing roadways may be difficult to undertake in certain areas due to the need for demolition of existing buildings, encroachment on residential neighborhoods, and physical impediments such as retaining walls, soundwalls, and overpass bridge supports. Depending upon the availability of usable space within the existing ROW and the severity of restrictions to lateral expansion beyond the ROW, lateral expansion can be costly and politically undesirable.

Traffic Impacts on Neighborhood Streets

In addition to the structural engineering difficulty of an extensive flyover ramp construction and the potentially high land acquisition costs to accommodate such facilities, the probable traffic impact on local streets could be a major issue. One of the potential adverse impacts of exclusive AHS entry and exit facilities is the potential for significant queuing of vehicles on local streets waiting to enter the automated facility. The basis for stating such concerns is that such queuing problems also exist under current traffic conditions at certain on- and off-ramps. With fewer exclusive AHS entry and exit facilities relative to currently existing on- and off-ramp densities, this situation could be exacerbated. Suitable sites such as large parking lots or undeveloped parcels where vehicles can queue up without interrupting local traffic should be investigated for exclusive entry and exit facilities. The availability of land would ultimately dictate site selection for entry/exit facilities.

Chapter 3. Rural Case Studies

Analysis of Rural Case Study Corridors

The implementation of AHS within three rural corridor segments in California were analyzed for two alternative deployment scenarios. The three corridor segments analyzed represent each of the three distinct rural corridor types identified earlier in this report. Segment 1 consists of approximately 20.9 kilometers (Los Angeles County Post Mile (PM) 55 to PM 68) of Interstate 5 located in the Tehachipi Mountains, between Los Angeles and Bakersfield. Segment 2 consists of approximately 16.1 kilometers (Merced County PM 30 to PM 32 and Stanislaus County PM 0 to PM 8) of I-5 in the northwestern portion of California's Central Valley. Segment 3 consists of approximately 31.0 kilometers (Stanislaus County PM 6 to PM 25) of California State Route 99 between Fresno and Sacramento.

Scenario One

Scenario one requires a minimum of eight lanes (four lanes in each direction), with automated and manual vehicles utilizing a common ROW. Under this scenario, the median, or left-most, lane would be the automated lane, the adjacent lane would be the transition lane, and the remaining lanes would be manual lanes. Concrete barriers between the transition lane and automated lane, with openings for entry and exit, and between the transition lane and adjacent manual lane, with large gaps for movement between these lanes, would be required under this scenario. Barriers would prevent accident debris from the manual lanes from entering the automated lanes and discourage illegal entry of manual vehicles into automated portions of the roadway. Barrier openings would allow for the possibility of the movement of vehicles from the automated lane to the transition and manual lanes in the case of a blockage in the automated lane. Barrier ends, despite being protected by crash cushions, would pose a safety hazard to vehicles changing lanes through barrier openings. Narrow buffers (i.e. 0.3 meter) between lane striping and barriers are recommended in areas where vehicles are operated under manual control. To access the automated lane, vehicles would enter the freeway via existing on- and off-ramps and then enter the automated lane through the transition lane following successful "check-in." To exit the automated lane, vehicles would enter the transition lane under automated control and then enter the manual lane under manual control following "check-out." Therefore, the construction of exclusive automated entry/exit facilities would not be required under this scenario. Access and egress points to and from the automated lane would be provided approximately every 3.5 kilometers at staggered "check-in" and "check-out" points along the transition lane.

The need for vehicles to weave through the manual lanes in order to gain access to the automated facility under this scenario may result in several operational problems. When the manual lanes are congested, accessibility of the automated facility would be hindered due to the difficulty in weaving through the manual lanes to access the automated facility. The capacity of the manual lanes would be reduced due to the increase in weaving activity between the right-most and left-most lanes. While congestion on rural highways is generally not a problem relative to the urban setting, congested conditions could exist in some locations.

Segment 1

There are four lanes in each direction throughout this segment. Approximately 9.7 kilometers of this segment consists of roadbeds with approximately 240 to 425 meters of lateral separation due to the mountainous terrain. The remainder of this segment, roughly 11.3 kilometers in length, contains a narrower median (including inside shoulders) of at least 9.2 meters, typically closer to 10.7 meters. Concrete barriers between the transition lane and automated lane and between the transition lane and adjacent manual lane are required under this scenario. The addition of these barriers (and possibly narrow buffers) would require a minimal amount of lateral expansion of the roadway. Along portions of this segment which consist of widely separated roadbeds, steep cuts and slopes are sometimes very close to the inside and outside shoulders. Where lateral expansion is required along a steep cut or slope portion of the roadway, the cost and difficulty of lateral expansion would increase. Within the portion of this segment in which the roadbeds are more closely spaced, the degree of lateral expansion required for this scenario would be relatively easy to accommodate within the median area due to the existing level grade of the median. Since no additional lanes are necessary within this segment and the median width is wide enough to accommodate the required degree of lateral expansion, reconstruction of overpasses would not be necessary. However, where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), if the existing inside and outside shoulder widths are maintained along these bridges, these structures would need to be widened slightly. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

Segment 2

There are two lanes in each direction throughout the length of this segment. The median width (including inside shoulders) is very constant throughout this segment, roughly 23 to 24.5 meters. Under this scenario, the roadway would need to be widened to accommodate two additional lanes in each direction, or a total of four additional lanes. In addition, concrete barriers between transition lanes and automated lanes and between transition lanes and adjacent manual lanes would need to be constructed. These barriers (and possibly narrow buffers) would require an additional amount of lateral expansion of the roadway. Due to the consistently wide median throughout this segment, the lateral expansion necessary to implement this scenario could be accommodated within the existing median. Therefore, expansion of the existing ROW and reconstruction of overpasses would not be necessary. However, along portions of this segment, steep cuts and slopes are sometimes very close to the inside shoulders. Where lateral expansion is required along a steep cut or slope portion of the roadway, the cost and difficulty of lateral expansion would increase. In addition, where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), these structures would require significant widening. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

Segment 3

The number of lanes and the median width along this segment vary significantly throughout its length.

Approximately 15 percent of this segment, 4.6 kilometers, has two lanes in each direction, with typical median widths of approximately 9.2, 24.4, and 30.5 meters in length representing 3, 5, and 8 percent of the total segment length, respectively. Three percent of this segment, 0.9 kilometer, has two lanes in one direction and three lanes in the opposite direction, with a typical median width of approximately 6.1 meters, representing 3 percent of total segment length. Eighty-two percent of the segment, 25.4 kilometers, has 3 lanes in each direction, with typical median widths of approximately 4.6, 6.1, 12.2, and 18.3 meters representing 8, 13, 49, and 13 percent of the total segment length, respectively.

Additional lanes would be needed to implement this scenario. Over 15 percent of this segment, 2 additional lanes in each direction, or a total of 4 lanes, would be needed. For three percent of this segment, a total of three additional lanes would be needed. Over the remaining 82 percent of this segment, 1 additional lane in each direction, or a total of 2 lanes, would be needed. In addition, concrete barriers between transition lanes and automated lanes and between transition lanes and adjacent manual lanes would need to be constructed. The addition of these barriers (and possibly narrow buffers) would require an additional amount of lateral expansion of the roadway. As outlined above, the median width throughout the majority of this segment is sufficiently wide to accommodate the lateral expansion required to implement this scenario. In areas where the median width is insufficient to accommodate the full extent of the required lateral expansion, the additional space needed is typically available within the existing ROW, beyond the outside shoulders.

In portions of this segment where lateral expansion beyond the outside shoulders is necessary, existing overpasses may not be wide enough to accommodate such expansion and therefore may need to be reconstructed. Additionally, where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), these structures would require significant widening, the extent of which varies with existing bridge widths. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

Scenario Two

Scenario two requires a minimum of six lanes (three lanes in each direction), with automated and manual vehicles utilizing a common ROW. In contrast to scenario one, the manual and automated lanes would be completely separated under this scenario; no movement between manual and automated lanes would be necessary or possible. Therefore, the operational problems associated with vehicles weaving between the manual and automated lanes under scenario one would not be encountered under this scenario. Under this scenario, the median, or left-most, lane would be the automated lane and the remaining lanes would be manual lanes. The automated lane would be completely separated from the manual lanes by a continuous concrete barrier. This barrier would prevent accident debris from the manual lanes from entering the automated lanes and prevent illegal entry of manual vehicles into the automated portion of the roadway. Since no barrier openings would exist, the movement of vehicles from the automated lane to the manual lanes in the case of a blockage in the automated lane would not be possible. Therefore, an emergency lane, or shoulder, adjacent to the automated lane is recommended in order to allow for the continued use of the automated lane in the case of a breakdown of a single automated vehicle or a minor incident in the automated lane and to provide emergency vehicle accessibility. Entry and exit to and from the automated lane would be from exclusive entry/exit facilities. Exclusive entry/exit facilities would consist of ramps connected to existing or newly constructed overpasses. Due to the cost associated with designing and constructing these exclusive entry/exit facilities, it is likely that accessibility to the automated facility would not be provided as frequently as in scenario one, in which existing on- and off-ramps are utilized and access to the automated lane is provided approximately every 3.5 kilometers. Likewise, egress points would not be provided as frequently as in scenario one.

Segment 1

Concrete barriers between manual lanes and automated lanes are required under this scenario. The addition of these barriers would require a minimal amount of lateral expansion of the roadway. For this scenario, emergency lanes/shoulders would be required adjacent to automated lanes. The minimum number of total lanes in each direction under this scenario is three lanes. Four lanes in each direction exist throughout this segment, so either one of the existing lanes could be converted to accommodate the emergency lane/shoulder and the lane barrier or the roadway could be expanded laterally to accommodate three manual lanes, one automated lane and the required infrastructure modifications. Under either of these two alternatives, overpasses not utilized as entry/exit facilities would not require reconstruction due to the sufficient width of median areas. If four lanes in each direction are maintained, the existing median widths throughout this segment would not be sufficient to accommodate access and egress lanes from overpass entry/exit facilities, which would merge and diverge into and out of the automated lanes from the center of the roadway. Where access/egress lanes are required, lateral expansion equivalent to approximately four lane widths would be required within the median area. By reducing the number of lanes in each direction to three, it is likely that these overpasses would not need to be reconstructed. However, since these overpasses would need to be modified to incorporate entry/exit facilities, it may be necessary to reconstruct them regardless of the number of lanes. Since the existing freeway ROW extends well beyond the outside shoulders, a significant degree of lateral expansion could be accommodated without requiring the acquisition of additional real estate; therefore, it may be worthwhile to maintain four lanes in each direction. Where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), if the existing inside and outside shoulder widths are maintained along these bridges, these structures would need to be widened under either alternative, albeit to a greater extent if four lanes in each direction are maintained. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant. If three manual lanes are provided in this segment, as opposed to two, the flow of traffic in the manual lanes would be much smoother, especially along steep grade sections, due to the varying speeds of heavy trucks and passenger cars.

Segment 2

Under this scenario, the roadway would need to be widened to accommodate one additional lane in each direction with adjacent emergency lanes/shoulders plus continuous concrete barriers between manual lanes and automated lanes. Due to the consistently wide median throughout this segment, this scenario could be accommodated within the existing median; therefore, the reconstruction of overpasses and expansion of the existing ROW would not be required. However, along portions of this segment, steep cuts and slopes are sometimes very close to the inside shoulders. Where lateral expansion is required along a steep cut or slope portion of the roadway, the cost and difficulty of lateral expansion would increase. In addition, where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), these structures would require significant widening. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

Segment 3

Additional lanes would need to be constructed along roughly 18 percent of this segment in order to implement this scenario, as compared with 100 percent to implement scenario one. For 15 percent of this segment, 1 additional lane in each direction, or a total of 2 lanes, would be needed. For three percent of this segment, one additional lane would be needed. Despite the fewer number of lanes required compared with scenario one, the ultimate roadway widths of the two scenarios would be very similar since emergency lanes/shoulders adjacent to the automated lanes would be required for this scenario. Continuous concrete barriers between manual lanes and automated lanes would also need to be constructed. As outlined above, the median width throughout the majority of this segment is wide enough to accommodate the lateral expansion required under this scenario. In areas where the median width is insufficient to accommodate the full extent of the required lateral expansion, the additional space needed is typically available within the existing ROW, beyond the outside shoulders.

In portions of this segment where lateral expansion beyond the outside shoulders is necessary, existing overpasses may not be wide enough to accommodate such expansion and therefore would need to be reconstructed. Additionally, where the freeway roadbeds consist of bridge structures (i.e. at underpasses and above drainage channels), these structures would require significant widening, the extent of which varies with existing bridge widths. Although the existing ROW is typically sufficient to accommodate the widening of bridge structures, the cost of such structural modifications would be significant.

Further Analysis Required

There are various trade-offs which must be considered to determine which of the two rural AHS scenarios discussed is preferable. At this point in AHS research, it is not possible to discern which of these two scenarios is most desirable for implementation. While it may be possible to determine which scenario is superior when comparing the two on the basis of a single criterion, such as safety, given the wide array of performance criteria which must be considered, it is not possible to make a determination of overall superiority at this time. Some of the issues which require further study include comparisons of cost, traffic operations, and safety.

Furthermore, due to the site specific nature of many of the issues in question, it is very difficult to make generalizations regarding the superiority of one scenario over the other. Depending upon the specific attributes of a given freeway corridor, the selection of the "best" scenario to implement may vary. For these reasons, specific recommendations for rural AHS deployment are not specified in this report. Rather, the issues and risks associated with the two deployment scenarios have been identified for further consideration.

CONCLUSIONS

In this report, issues and risks associated with the deployment of automated highway systems in both urban and rural freeway corridors in California were identified. A range of AHS deployment scenarios were identified and examined in the context of case study analyses. The urban case study corridor analyzed consists of a 52 km segment of U.S. Route 101 in Los Angeles. Examination of rural issues was conducted through the analysis of three rural freeway segments. The three rural segments analyzed represent each of the distinct rural corridor types identified in Chapter 1, "Rural Corridor Analysis." While the issues presented were directly related to those AHS deployment concepts examined for the case study corridors, they are hopefully general enough so as to provide valuable information applicable in other corridors. Local conditions dictate, however, the feasibility of implementing each alternative deployment option requiring a case by case evaluation for each candidate corridor.

At-grade, above-grade, and below-grade AHS deployment concepts were examined in the context of the case study corridors. In both urban and rural environments, deployment of at-grade AHS facilities is the most desirable of the options examined. Compared to at-grade AHS facilities, above- and below-grade AHS facilities would typically be more costly to construct and would introduce greater seismic safety hazards. Furthermore, above-grade facilities would result in negative visual/aesthetic impacts and high concentrations of vehicle exhaust pollutants within below-grade facilities may pose a safety hazard. Despite the apparent advantages of the at-grade concept, there are situations in which the deployment of either the above- or below-grade concepts may be more sensible. In densely developed urban environments the acquisition of additional ROW is often extremely costly; therefore, if additional ROW is necessary to deploy an at-grade AHS facility, deployment of either an above- or below-grade AHS facility may be less costly as well as less disruptive in terms of land use displacement. Freeway-to-freeway splits and merges at complex interchanges may require additional infrastructural improvements in order to facilitate the uninterrupted flow of automated traffic streams. In order to accomplish this objective, construction of multi-level interchanges may be necessary, thereby requiring the deployment of either the above- or below-grade option, or a combination of both concepts.

The at-grade AHS deployment concept can be broken down into two distinct design alternatives, the shared geometric configuration and the dedicated geometric configuration. In the shared geometric configuration, vehicles enter the automated lane(s) from the manual (conventional, non-automated) lanes through a transition lane and therefore existing conventional on- and off-ramps are utilized. In the dedicated geometric configuration, no movement occurs between the manual and automated lanes and entry/exit to and from the AHS facility is provided via dedicated entry/exit facilities. In terms of safety and freeway traffic operations, the complete separation of manual and automated traffic appears to be more desirable. However, there are tradeoffs between these two design alternatives which should be studied further in order to determine which alternative is most desirable overall. Comparisons between the two alternatives which should be investigated further include cost, safety, land use displacement, freeway traffic operations, impacts to local street traffic, and accessibility to the automated facility by emergency vehicles.

Based on the results of the case study analyses, with varying degrees of difficulty AHS can be integrated into existing freeway facilities, i.e., there are no apparent constraints which would preclude AHS deployment within existing freeway corridors. Due to the highly restrictive and complex nature of the urban case study corridor analyzed, the ability to integrate AHS within this corridor suggests that AHS can be deployed in similarly "difficult" corridors. Based on the results of the rural case study analyses, the integration of AHS within rural freeway corridors can be achieved with fewer difficulties than urban corridors. The typically wide existing rights-of-way of rural freeway corridors would, in general, allow for the deployment of at-grade AHS facilities with few complications, particularly in areas with relatively flat terrain.

In addition to the fairly microscopic issues of AHS infrastructure deployment which require further study, there are several more macroscopic issues which must be addressed prior to AHS deployment. The incremental development, or phasing, of AHS facilities in relation to market behavior needs to be explored. Further studies must be conducted in order to determine whether or not AHS facilities should accommodate both light-duty and heavy-duty vehicles and, if so, to determine whether or not such a system is technically viable. In general, additional detailed studies addressing numerous facets of AHS are needed in order to adequately assess the overall desirability and feasibility of wide-scale AHS deployment.

APPENDIX 1

METHODOLOGY USED TO IDENTIFY CANDIDATE URBAN CORRIDORS

Caltrans' SMART Corridor Statewide Study, Final Report was utilized as a starting point in identifying candidate urban corridors.[3] All 120 or so corridors identified in the SMART Corridor Study were considered as candidate corridors for this study. Consistent with the SMART Corridor Study, corridors from the less congested Caltrans districts of the State were not considered. Therefore, the Caltrans districts considered for candidate urban corridors for this study, consistent with the SMART Corridor Study, were as follows: District 3 - Sacramento Area; District 4 -San Francisco Bay Region; District 7 -Los Angeles & Ventura Counties; District 8 - San Bernardino & Riverside Counties; District 11 - San Diego Area; and, District 12 - Orange County.

The following preliminary criteria for the selection of candidate urban corridors were established: All candidate corridors must be a minimum of four lanes total; unconstructed corridors would not be considered since no traffic data is available for these corridors; and, only limited rural segments would be permitted as part of candidate urban corridors.

The Caltrans 1992 Route Segment Report was obtained both in hardcopy and on disk from Caltrans. This report served as a primary database for roadway characteristics, congestion, and safety-related information for all candidate corridors. An edited version of the entire database was created consisting of data for the candidate corridors only, having deleted most of the two-lane, unconstructed, mountainous, and rural highway segments from the database. Highway segments located in Caltrans districts not under consideration for candidate corridors were also deleted. After these preliminary revisions were made to the database, a revised hardcopy printout of the edited database file was made.

Initially, each of the individual corridors identified in the SMART Corridor Study on the edited database printout were identified. At this early stage of the corridor selection process, no maximum corridor length was set. Where two or more corridors identified in the SMART Corridor Study were contiguous along a single route, these corridors were combined into a single corridor. In addition, corridors were lengthened to the fullest extent possible within the urbanized area boundaries identified on the Caltrans State Highway Map (1990). Where corridors passed through non-urbanized areas for distances of approximately 1.6 to 3.2 km, these segments were included as part of the corridor in order to maintain the continuity of the corridor. However, where a corridor passed through a non-urbanized area for a distance of several kilometers or more, the corridor was divided into two smaller corridors separated by the rural segments.

Additional candidate urban corridors of at least 8 km in length within the Caltrans districts under consideration were identified which had not been previously identified in the SMART Corridor Study.

All highway segments not included as part of the revised list of candidate urban corridors were subsequently deleted. A total of 55 candidate urban corridors were identified, ranging in length from 8.7 to 155.8 km. A printout of the revised database was made for further study and analysis.

After further review of the 55 candidate urban corridors, 3 corridors were eliminated which were comprised of portions of SR 1, Pacific Coast Highway. It was concluded that SR 1 would not be suitable for automation for the following reasons: 1) SR 1 is heavily travelled by tourists and sightseers, often in large recreational vehicles and typically at low speeds, especially during the summer months, and 2) the configuration of SR 1 varies widely, ranging from full access controlled freeway portions which overlap with highway U.S. 101 to two-lane signalized arterials with pedestrian activity. After the elimination of these 3 corridors, the total number of candidate urban corridors was reduced to 52.

APPENDIX 2

METHODOLOGY USED IN CALTRANS PHOTOLOG REVIEW

As part of the analysis and classification of the 52 candidate urban corridors, Caltrans' photolog of highways was utilized to obtain information pertaining to the existing highway infrastructure unavailable from other sources. The use of Caltrans' photolog enabled detailed observations of the candidate corridors by precise postmile markings. Noted information included the location and distribution of various physical features of highway infrastructure and other features in proximity to the highways.

Precise locations of those physical features that represented an apparent constraint to lateral or longitudinal expansion of the existing highway facilities were recorded. Such features consisted of vehicle overpasses, pedestrian overpasses, railroad overpasses, soundwalls, retaining walls, frontage roads, land use restrictions, tunnels, and major bridges. This group of physical features represented nearly all of the existing physical restrictions to lateral and longitudinal expansion of existing freeway facilities. The land use restriction category is comprised of more than one specific physical feature. Restrictions to lateral expansion identified as land use restrictions included structures (residential, commercial, industrial), parking lots, bodies of water (other than major bridges), and rail lines (heavy rail and rapid rail transit). In addition, the location of HOV lanes were denoted and details of the type(s) of terrain that the corridors pass through were recorded.

The criteria used in judging whether or not a physical feature represented a constraint to lateral expansion is whether or not an adequate amount of space was available to construct a single 3.1 to 3.7 meter traffic lane between the existing outside shoulder and the physical feature in question within the existing freeway ROW. Accordingly, soundwall, retaining wall, frontage road, and land use restrictions were only recorded in locations where they did not appear to be set back an adequate distance from the edge of the outside shoulder to allow for the construction of an additional traffic lane. In areas where the distance between the edge of the outside shoulder and the physical feature appeared to be adequate to accommodate an additional traffic lane, but where the steepness of a cut or slope within this area would cause a problem if graded, such as in a case where an embankment is supporting a soundwall on top of the slope, then this was considered a restriction to lateral expansion and denoted as such.

The precise starting and end points of a number of corridors were adjusted as a result of the information derived from the photolog review in order to remain consistent with the original parameters for the establishment of the corridors. For example, signalized portions of corridors were eliminated where applicable, typically at the beginning or ending of a corridor before the freeway begins or after the freeway ends. As a result of these adjustments, Corridor #23, Route 73 in District 12, was eliminated since its total length after being adjusted fell below the established minimum corridor length of approximately 8 km. Therefore, the number of candidate urban corridors was reduced to 51. In addition, Corridor #52, a loop surrounding downtown Los Angeles in District 7 comprised of four separate highways was eliminated after further consideration. It was decided that since this corridor was comprised of small segments of other corridors already under consideration and because it was the only candidate corridor consisting of more than one highway it should be eliminated from consideration as a candidate urban corridor. Therefore, the number of candidate urban corridors was further reduced to 50.

Information was recorded pertaining to the type(s) of terrain that the corridors pass through since the natural terrain of a highway alignment significantly affects the ease and cost of lateral expansion. For example, highways which pass through very hilly topography typically require significant cutting and filling in order to meet horizontal and vertical curve standards throughout the length of the highway. Along portions of highways with steep cuts and slopes, lateral expansion is often very difficult and costly, and in some cases may not be possible at all. Furthermore, depending upon the steepness of the cuts and slopes and the specific soil characteristics, it may be necessary to construct expensive retaining walls in order to accommodate lateral expansion of highways. At the other extreme, in flat urban areas, full access-controlled freeways require a large amount of expensive earthwork in order to avoid at-grade intersections with vehicular and railroad routes. In flat urban areas, many highways contain depressed and/or elevated portions and at intersections must be depressed below intersecting routes or elevated above them. In flat areas, where highways are elevated and/or depressed, lateral expansion can be very difficult and costly. A numerical rating scale was developed for recording information pertaining to terrain based on the Caltrans Photolog review. The scale used ranged from 1 to 5; 1 representing very flat terrain; 2 representing fairly flat, gently rolling terrain; 3 representing moderately hilly, rolling terrain; 4 representing hilly terrain with a significant amount of steep slopes; and 5 representing very hilly terrain with many very steep slopes. In addition, information pertaining to the distribution of the various types of terrain, the degree of the setbacks of the slopes from the edge of the outside shoulder of the highway, and the degree of symmetry of the terrain along both sides of the highway was also recorded.

Due to the significant number of recent additions of HOV lanes throughout the State of California, an up-to-date list of existing HOV lanes in the State was obtained from Caltrans. The HOV lane information obtained from the review of the Caltrans Photolog was subsequently checked and reviewed.

APPENDIX 3

CONSTRAINTS TO PHOTOLOG USE FOR CORRIDOR ANALYSIS

Since a wide angle camera lens was used to film the highways and the majority of the footage was filmed from the middle lanes, depth perception on the periphery of the highways was distorted. Therefore, it was difficult to precisely determine the extent of the restrictions to lateral expansion of the highways simply by viewing the photolog footage. For example, in areas where soundwalls were located beyond the outside shoulder of the highway, in many instances it was difficult to determine how far the wall was set back from the edge of the shoulder. Therefore, in such situations, it was difficult to determine whether or not such physical features represented a restriction to lateral expansion.

In areas where vegetation along the edge of the highway was very dense and tall, it was very difficult, and sometimes impossible, to see what existed beyond the vegetation, such as soundwalls, frontage roads, retaining walls, land use restrictions, and so on. Therefore, where the density and height of the vegetation obstructed the view of the observer, it was very possible that restrictions which were in fact present could not be seen on the photolog.

In many areas where the highways were either elevated or depressed, it was difficult to judge the extent of potential restrictions to lateral expansion. Along segments of highways which were depressed, it was often difficult to see beyond the top of the cut, where, for example, a frontage road or land use restriction may have been present. Similarly, along segments of highways which were elevated, it was often difficult to detect whether or not restrictions to lateral expansion were present on the ground level.

Since the Caltrans photolog footage is updated in phases, with each Caltrans district updated every three years, it is likely that there were features along a number of the highways which were actually present but were not reflected in the current photolog footage. For the most part, the footage viewed was filmed between 1989 and 1992. Therefore, it was unlikely that a significant number of major changes have been made to these freeways since the time that the footage was filmed. However, the footage of District 4 (San Francisco Bay Area) freeways viewed was filmed between 1986 and 1987, with the exception of Route 80 and Route 580 which were filmed in 1992 and 1991, respectively. It was also realized that many of the existing HOV lanes in the State would not be included in the photolog footage due to an on-going HOV lane construction program. Locations of existing HOV lanes in the State were obtained from Caltrans in January 1994. The HOV lane information obtained from the review of the Caltrans photolog was subsequently checked and updated.

In many instances, the current photolog footage was filmed during periods of construction along the highways. Such construction activities included realignment of portions of highways, construction of new overpasses, soundwalls, HOV lanes, and other construction, and highway widening. In many such cases, it was difficult to tell exactly what was being done or what existed along the edge of the highway due to the early stage of construction activities and temporary barriers and fences which obstructed the view of the highway and its setting. Therefore, in areas where construction activities were in progress during the filming of the photolog footage, it was likely that features which were under construction were not identified properly or at all and that restrictions to lateral expansion were not identified due to temporary obstructions to views along the edge of the highway.

APPENDIX 4

METHODOLOGY USED IN FIRST STAGE ELIMINATION OF CANDIDATE URBAN CORRIDORS

The original photolog data sheets were reviewed for each of the fifty candidate corridors relative to each of the following nine physical features: vehicle overpasses, pedestrian overpasses, railroad overpasses, soundwall restrictions, retaining wall restrictions, land use restrictions, frontage road restrictions, tunnels, and HOV lanes. It was determined which of the 50 candidate corridors possessed which of the 9 features. At this point in the analysis, it was determined which features were common to a majority of the 50 corridors. Of the 9 physical features considered, the following 6 were common to at least half of the 50 candidate urban corridors: vehicle overpass, pedestrian overpass, soundwall restriction, retaining wall restriction, land use restriction, and frontage road restriction. These six features were considered the most representative of the features.

The objective of the research was to select a case study urban corridor which was representative of the urban freeways within California and which also contain some additional features which would facilitate a comprehensive analysis of the issues associated with AHS deployment. Therefore, the intent of the first stage elimination of candidate urban corridors was to eliminate those corridors which clearly were not representative of typical urban freeways in California as well as those corridors which did not contain at least a minimal level of diversity of features.

Prior to making a final determination to eliminate any of the 50 candidate urban corridors, a final review was made of the data recorded for the corridors based on the Caltrans photolog as well as the corridors' locations on a map in order to make certain that the corridors did not possess any significant value as a potential case study urban corridor that may have been previously overlooked.

Those corridors which contained four or less of the nine features listed above should be eliminated due to their clear lack of diversity and representativeness. Those corridors which contained five of the nine physical features were then considered. Of these corridors, one corridor contained three features common to a majority of the corridors and three corridors contained four of the six common features. The one corridor (Corridor #28, Route 92) which contained three of the common physical features was eliminated due to its lack of representativeness both in terms of the limited number of common features that it possessed and also due to the fact that approximately one-half of the corridor's length consisted of a major bridge structure, the San Mateo Bridge in the San Francisco Bay Area, a feature that is not at all typical of the freeways in California. After reviewing the three corridors which contained four of the six common features, two of the three corridors were eliminated. Corridor #48, Route 710 in District 7, was not eliminated since it is a highway which has been associated with a significant amount of political controversy in recent years due to proposed plans on behalf of Caltrans/Federal Highway Administration to extend the highway through the established community of South Pasadena in southern California. It was felt that the circumstances surrounding this highway would possibly lend itself well to analysis as a case study corridor because of the unique issues that would be involved in automating and possibly extending this corridor in the future. The remaining corridors possessing five features, all of which were features common to a majority of the corridors were not be eliminated at this stage of the analysis. It was concluded that more detailed information should be reviewed prior to the elimination of these corridors.

At the conclusion of the first stage elimination, 22 of the 50 candidate urban corridors were eliminated, leaving 28 candidate urban corridors for further consideration. These 28 corridors were renumbered from 1 to 28, numbered in order beginning with the lowest route number and ending with the highest route number.

APPENDIX 5

METHODOLOGY USED IN THE ANALYSIS OF DATA CONTAINED IN THE 1992 CALIFORNIA STATE HIGHWAY LOG REPORTS

For each of the 28 candidate urban corridors under consideration after the first stage of elimination, further analysis of the physical features of these freeway facilities were performed. Utilizing data contained in the 1992 California State Highway Log reports, data pertaining to the number of lanes per direction and median width for each of the candidate corridors were analyzed.

The proportion of the total length of each corridor in each direction that is comprised of varying numbers of lanes was calculated.

The proportion of the total length of each corridor with median widths that fell within each of the following ranges was calculated: less than 4.9 meters; between 4.9 meters and 8.5 meters; between 8.5 meters and 12.2 meters; between 12.2 meters and 15.9 meters; and greater than 15.9 meters. These median width ranges were established on the basis of accommodating additional traffic lanes within the medians of these corridors. The width for automated highway lanes is likely to be less than the current accepted standard width of 3.7 meters for a freeway traffic lane due to the vehicle's automatic steering or lateral control capability. A value of 3.7 meters was used in this analysis to err on the conservative side.

Furthermore, since the conversion of a median to traffic lanes would in most cases require the construction of a barrier to divide the two directions of traffic, an additional 1.2 meters, the generally accepted minimum median width for a freeway facility, was added to each of the median width ranges to allow for such a structure. Each of the aforementioned median width categories used in the analysis represents the potential for the expansion of the corridors by increasing numbers of lanes, beginning with the maximum potential for the expansion of zero lanes in the "less than 4.9 meters" category and increasing by one lane per category up to the "greater than 15.9 meters" category in which the potential for expansion is at least four lanes, provided that there are no physical constraints to lateral expansion within the median, such as very steep slopes.

The highway log reports specify whether the median width is either constant or variable for each highway segment listed. Where the median width is listed as variable, the minimum width within the segment is given and the maximum width within the segment could be as great as 30.2 meters. Distinct notation is used in the highway log reports when the median width is 30.5 meters or greater. For the purposes of this analysis, it was determined that segments containing variable and constant median widths should be analyzed together since it is the minimum median width within each segment that is of prime importance in terms of the addition of traffic lanes within the median. Furthermore, from the data available, it is not possible to determine the range or distribution of the median widths within those segments that are denoted as variable.

APPENDIX 6

PHYSICAL FEATURES FOR CANDIDATE URBAN CORRIDORS

Corridor Number	Route	Length (km)	Caltrans District	Vehicle Overpass Density (#/km)	Pedestrian Overpass Density (#/km)	Railroad Overpass Density (#/km)	Retaining Walls (%/%)	Sound Walls (%/%)	Frontage Roads (%/%)	Land Use Restrictions (%/%)	Tunnels (%)	HOV (%)	Terrain Type	1-Lane In Median (%)	2-Lanes In Median (%)	3-Lanes In Median (%)	4-lanes/ Direction (%)	5-lanes/ Direction (%)
1	5	155.8	12/7	0.75	0.06	0.02	1.3/2.9	1.1/14.8	2.6/3.9	6.7/3.8	0	9.3/9.3	1-5	72.9	28.8	24.9	68	16.2
2	8	38.2	11	0.55	0.02	0.05	5.9/0.4	1.3/3.6	1.7/0.8	0/0	0	0.0/0.0	2-4	98.2	39.9	37.9	65.4	28.8
3	10	137.3	7/8	0.63	0.06	0.01	0.9/1.3	12.7/14.2	3.3/3.1	4.8/22.8	0	15.7/14.2	1-5	97.6	36.2	8.2	86	22
4	22	21.3	12	0.38	0.05	0	0.8/0.0	6.1/0.8	0.0/0.0	0.0/24.2	0	0.0/0.0	1	100	8.4	7.4	1.1	0
5	55	25.1	12	0.95	0	0	9.6/12.1	1.3/8.9	1.9/1.9	5.1/0.3	0	78.3/78.3	1-2	36.4	17.9	5.7	82.3	22.3
6	57	31.6	12/7	0.53	0.03	0	1.0/0.0	17.7/8.0	0.0/0.0	7.0/0.7	0	59.2/59.2	1-5	56.2	18.4	3.5	91.8	54.8
7	60	85.0	7/8	0.46	0.09	0	0.4/0.4	6.0/6.0	2.1/10.1	2.6/3.1	0	0.0/0.0	1-5	84.5	52.3	51	50.7	22.1
8	80	45.2	4	0.37	0.02	0	1.1/0.0	0.7/0.7	1.1/0.9	1.4/5.3	0.7/0.4	0.0/11.0	1-4	34.7	32.7	31.4	44.3	24.6
9	80	44.6	3	0.68	0.02	0	0.0/0.0	4.8/15.4	0.7/1.5	7.0/1.1	0	0.0/0.0	1	100	77.4	71	36.4	12
10	91	88.9	7/12/8	0.49	0.03	0.02	0.3/0.8	7.3/10.0	0.3/0.8	1.7/3.0	0	32.9/36.5	1-5	88.9	29.8	25.6	70.5	24.9
11	99	15.3	3	0.73	0.25	0	0.0/0.0	63.8/46.8	0.0/22.3	0.0/8.5	0	41.5/0.0	1-2	100	31.3	29.8	48.6	0
12	101	52.2	7	0.73	0.06	0.02	8.5/7.3	8.2/8.8	0.6/2.5	7.7/1.2	0	0.0/0.0	1-4	36.1	7.5	6.7	88.1	9.3
13	101	60.1	7	0.48	0.02	0.02	0.8/0.5	2.9/2.4	28.4/21.2	0.5/0.3	0	0.0/0.0	1-5	100	63.6	33.3	38.7	16.7
14	101	110.8	4	0.74	0.08	0.02	1.4/0.9	5.6/5.2	12.2/27.9	5.1/9.6	0	46.6/46.6	1-4	69.2	36.4	21.1	71.7	6.4
15	101	39.1	4	0.33	0.07	0	0.2/0.4	4.6/2.9	10.4/28.2	8.9/25.1	0.8/0.8	40.7/39.8	2-5	65.8	26.5	22.4	61.7	8.6
16	101	30.1	4	0.47	0.07	0	0.0/0.0	0.0/0.5	9.6/12.8	0.0/18.4	0	0.0/0.0	1-4	100	100	81.9	0	0
17	110	51.0	7	1.57	0.1	0.04	7.8/2.4	5.5/3.2	6.6/0.0	14.9/12.7	0.0/1.0	0.0/0.0	1	75.6	10.8	10	63.6	10.5
18	118	40.4	7	0.67	0.02	0	0.0/2.4	1.6/6.0	0.0/0.8	0.0/0.0	0	0.0/0.0	2-5	100	100	61.9	28.3	9.9
19	163	14.2	11	0.91	0.07	0	2.8/3.4	0.0/0.0	10.1/3.4	0.0/2.2	0	2.2/2.2	1-2	91	48.1	9.3	85.4	31.1
20	170	9.8	7	0.61	0.1	0	4.9/0.0	0.0/3.3	0.0/0.0	0.0/3.3	0	0.0/0.0	1	100	5.4	5.4	77.3	14.6
21	210	78.1	7	0.68	0.09	0	0.8/5.5	9.4/15.6	0.0/0.0	0.0/5.2	0	38.0/38.0	1-5	100	100	18.5	86.9	26.5
22	280	88.7	4	0.69	0.1	0	6.3/4.1	0.0/1.2	0.4/2.8	7.3/0.4	0.2/0.0	20.0/17.0	1-4	96.4	72.5	24.3	95.1	21.3
23	405	116.4	12/7	0.74	0.02	0	2.4/1.2	15.2/16.9	0.7/0.0	0.0/0.1	0	46.2/43.2	1-5	66.8	8	6.2	94.6	49.3
24	580	83.2	4	0.59	0.04	0	4.9/2.9	3.7/3.5	7.8/10.3	0.3/0.4	0	10.5/10.5	1-5	96.2	80.7	57.2	74.1	5.1
25	605	44.1	12/7	0.48	0.04	0.02	0.0/0.4	12.3/23.3	0.7/0.0	1.1/0.7	0	0.0/0.0	1	87.1	40.6	2.3	92.7	16.7
26	680	93.2	4	0.37	0.04	0.01	0.3/0.3	2.6/2.2	0.9/0.9	3.4/0.3	0	0.0/0.0	1-4	95.6	69.3	41.4	21.4	0.2
27	710	33.2	7	1.09	0	0.22	0.5/1.9	18.0/7.3	0.0/0.0	1.5/1.5	0	0.0/0.0	1	91.9	17.8	17.8	66.1	11.4
28	880	72.5	4	0.69	0.01	0	0.1/0.0	3.6/3.6	8.7/2.4	14.1/18.5	0	15.4/15.4	1	67.8	19	18.4	37.6	6.7

Terrain type code: 1: very flat 2: fairly flat, gently rolling terrain 3: moderately hilly, rolling terrain 4: hilly with many steep slopes 5: very hilly, many very steep slopes

APPENDIX 7

OVERVIEW OF PRELIMINARY RURAL CORRIDOR ANALYSIS

A total of seven rural (intercity) highway corridors were selected for potential use in the rural case study analysis. Films of these seven corridors from Caltrans' Photolog Film Library were reviewed to determine the various characteristics of rural highway corridors throughout California. The information derived from the review of the films of these seven rural corridors is outlined below.

CORRIDOR #1

Corridor #1 consists of the 25.8 kilometer segment of Interstate 5 (PM 56 through PM 72) in San Diego County connecting the urbanized regions of San Diego and Los Angeles/Orange County. The characteristics of this corridor are very uniform throughout. The terrain is fairly flat with gently rolling landscape. There are fairly wide median widths with narrower median widths along some short segments. No evident land use restrictions to lateral roadway expansion are present. A single truck stop was the only land use observed along the highway. Other notable observations consisted of surrounding landscape comprised primarily of scrubbrush vegetation. Overpasses are located at Post Miles 58 (2 overpasses) and 71.

CORRIDOR #2

Corridor #2 consists of the 444.4 kilometer portion of Interstate 5 and the 37.0 kilometer portion of Route 580 which connect the urbanized regions of Los Angeles and the San Francisco Bay Area.

In Los Angeles County (PM 52 through PM 88), the characteristics of this portion of Interstate 5 are very uniform throughout with mountainous terrain. There are fairly narrow median widths throughout a majority of the corridor; where median areas are wide, the separated roadbeds are typically at different elevations making lateral expansion of the highway more difficult. The majority of median areas are paved, contain a narrow drainage channel in the center and do not contain median barriers or guardrails. Few land use restrictions to lateral roadway expansion are evident; land uses are scattered throughout the corridor. Other notable observations include frontage roads, although they do not appear to pose a restriction to lateral expansion of the highway. Overpasses are located at Pos Miles 52, 55, 56 (2 overpasses), 59, and 64.

Traveling north, in Kern County (PM 0 through PM 10), the characteristics of this portion of Interstate 5 are very uniform throughout with mountainous terrain. There are fairly narrow median widths throughout a majority of this portion of the corridor; where median areas are wide, the separated roadbeds are typically at different elevations making lateral expansion of the highway more difficult. No land use restrictions to lateral expansion are evident. Overpasses are located at Post Miles 4 and 5.

Continuing on Interstate 5 in Kern County (PM 10 through PM 87), the characteristics of this portion are again fairly uniform throughout. For this segment of the corridor, the terrain is very flat. Median area characteristics consist of fairly narrow median widths from PM 10 to PM 15 and fairly wide median widths throughout the remainder of this portion of the corridor. No land use restrictions to lateral expansion are evident. There are essentially no land uses evident other than one major highway interchange at PM 52 containing traveler services, such as motels, restaurants, and gas stations. Other notable observations include frontage roads, although they do not appear to pose a restriction to lateral expansion of the highway. Lands along this portion of the corridor consist primarily of cultivated and fallow farmlands and scrubbrush vegetation. Overpasses are located at Post Miles 12, 13, 17, 20, 21, 22, 26, 28, 29, 33, 36, 39, 41, 43, 45, 47, 56, 58, 62, 65, 68, 69, 73, 77, 80, 82, and 87.

In Kings County (PM 0 through PM 27), the characteristics of this portion of Interstate 5 are fairly uniform throughout. Terrain consists of rolling hills from PM 15 to PM 25; otherwise, the terrain of this portion of the corridor is essentially flat. Median characteristics consist of fairly wide median widths, with the exception of the hillier areas where median widths are wider and where separated roadbeds are at different elevations making lateral expansion more difficult. No land use restrictions to lateral expansion are evident. Other notable observations include lands along this portion of the corridor that consist primarily of cultivated and fallow farmlands and scrubbrush vegetation. Overpass Post Miles are located at 4, 7, 12, 14, 19, 24, and 26.

In Fresno County (PM 0 through PM 66), the characteristics of this portion of the corridor are fairly uniform throughout. Terrain consists of rolling hills from PM 18 to PM 22; otherwise, the terrain of this portion of the corridor is essentially flat. Median characteristics consist of fairly wide median widths, with the exception of the hillier areas where median widths are wider and where separated roadbeds are at different elevations making lateral expansion more difficult. No land use restrictions to lateral expansion are evident. From PM 0 to PM 22, surrounding lands consist primarily of cultivated and fallow farmlands; the remainder of this portion of the corridor consists primarily of scrubbrush vegetation. Overpasses are located at Post Miles 0, 5 11, 15, 18, 21, 24, 30, 38, 41, 43, 46, 49, 52, 60, 65, and 66.

In Merced County (PM 0 through PM 32), the characteristics of this portion are very uniform throughout. The overall terrain consists of rolling hills; the majority of this portion of the corridor is adjacent to the foothills of the Coast Ranges to the west and is typically flatter to the east. Median characteristics consist of fairly wide median widths, with the exception of the hillier areas where median widths are wider and where separated roadbeds are at different elevations making lateral expansion more difficult. No land use restrictions to lateral expansion are evident; essentially no land uses exist other than traveler services, such as motels, restaurants, and gas stations located near major highway interchanges. Other notable observations include surrounding lands consisting primarily of cultivated and fallow farmlands. The California Aqueduct is located in the vicinity. Overpasses are located at Post Miles 6, 9, 12, 21, 22, 23, 24, 26, 28, 30, and 32.

In Stanislaus County (PM 0 through PM 28), the characteristics of this portion are very uniform throughout. The overall terrain consists of gently rolling hills; some portions are adjacent to the foothills of the Coast Ranges to the west and is typically flatter to the east. Median characteristics consist of fairly wide median widths, with the exception of the hillier areas where median widths are wider and where separated roadbeds are at different elevations making lateral expansion more difficult. No land use restrictions to lateral expansion are evident; essentially no land uses exist other than traveler services, such as motels, restaurants, and gas stations located near major highway interchanges. Other notable observations include surrounding lands consisting primarily of cultivated and fallow farmlands, including many orchards. The California Aqueduct is located in the vicinity and is fairly close to the highway in some areas. Overpasses are located at Post Miles 1, 5, 7, and 9.

On Interstate 580 in San Joaquin County (PM 0 through PM 15), the characteristics of this portion of the corridor are fairly uniform throughout. This portion of the corridor consists of flat to gently rolling terrain. Median characteristics consist of fairly wide median widths. No land use restrictions to lateral expansion are evident. Other notable observations include surrounding lands containing limited farmlands. The California Aqueduct is located in the vicinity and is fairly close to the highway in some areas. Overpasses are located at Post Miles 1, 4(2), 6, 8, and 13.

In Alameda County (PM 0 through PM 8), the characteristics of this portion of the corridor are fairly uniform throughout. This portion of the corridor consists of rolling to hilly terrain. Nearly all of this portion of the corridor consists of separated roadbeds due to the hilly terrain where roadbeds are separated, median widths are fairly wide and the roadbeds are at different elevations making lateral expansion difficult; a short segment where the roadbeds are not separated contains no available median area. No land use restrictions to lateral expansion are evident. Other notable observations include the presence of many windmill power generators. One overpass is located at Post Mile 6.

CORRIDOR #3

Corridor #3 consists of the 90.2 kilometer portion of Interstate 5 and the 27.4 kilometer portion of State Route 99 which connect the urbanized regions of Los Angeles and Bakersfield.

On Interstate 5 for Post Miles 52 through 88 in Los Angeles County and for Post Miles 0 through 20 in Kern County, these are the same areas covered under Corridor #2.

In Kern County on SR 99 (PM 0 through PM 17), the characteristics of this portion of the corridor are very uniform throughout, with very flat terrain. Median characteristics consist of fairly wide median widths. No land use restrictions to lateral expansion are evident; some minor land uses exist. Other notable observations include frontage roads, although they do not appear to pose a restriction to lateral expansion of the highway. Land uses along this portion of the corridor consist primarily of cultivated and fallow farmlands. Overpasses are located at Post Miles 0, 2, 5, 7, 9, 11, 13, 15, and 17.

CORRIDOR #4

Corridor #4 consists of the 88.6 kilometer portion of Route 15 which connects the urbanized regions of San Diego and Los Angeles/Orange County.

In San Diego County (PM 36 through PM 54), the characteristics of this portion of the corridor are fairly uniform throughout with mountainous terrain. Median characteristics consist of fairly wide median widths, with the exception of the hillier areas where median widths are wider and where separated roadbeds are at different elevations making lateral expansion more difficult. No land use restrictions to lateral expansion are evident; no land uses exist. Overpasses are located at Post Miles 36, 43, 44, 46, 47, 50, and 54.

In Riverside County (PM 0 through PM 37), the characteristics of this portion of the corridor vary throughout. Terrain is mountainous from PM 0 to PM 3, fairly flat to rolling hills from PM 3 to PM 24, then hilly for the remainder of this portion of the corridor. There are fairly wide median widths throughout, with the exception of the hillier areas where median widths are wider and where separated roadbeds are at different elevations making lateral expansion more difficult. Only a few land use restrictions to lateral expansion are evident; some industrial, commercial and residential land uses are scattered throughout. Other notable observations include frontage roads and soundwalls, although they do not appear to pose a restriction to lateral expansion of the highway. Overpasses are located at Post Miles 4, 5, 6, 9(2), 10, 14, 15, 20, 24, and 37.

CORRIDOR #5

Corridor #5 consists of the 77.3 kilometer portion of Interstate 80 which connects the urbanized regions of the San Francisco Bay Area and Sacramento.

In Solano County (PM 6 through PM 44), characteristics of this portion of the corridor vary throughout. Terrain is mountainous for the first several kilometers, then fairly flat for most of the remainder of this portion of the corridor, with the exception of one hilly segment from PM 21 to PM 25 and one flat to gently rolling segment from PM 25 to PM 32. There is no usable median space from PM 6 to PM 8, separated roadbeds from PM 8 to PM 10, no usable median space from PM 10 to PM 12, fairly wide median from PM 12 to PM 14, no usable median space from PM 14 to PM 17, wide median from PM 17 to PM 22, separated roadbeds from PM 22 to PM 23, and fairly wide median from PM 23 to PM 44. Median areas along segments with separated roadbeds are more difficult to utilize for lateral expansion since roadbeds are typically at different elevations. No land use restrictions to lateral expansion are evident; some industrial, commercial and residential land uses are scattered throughout. Other notable observations include frontage roads and soundwalls. Frontage roads do not appear to pose a restriction to lateral expansion of the highway while soundwalls appear to pose some restrictions. Farmlands are interspersed with other scattered land uses along several lengthy segments of this portion of the corridor. Overpasses are located at Post Miles 8, 12(2), 13(3), 16(2), 18(2), 19, 20, 23, 24, 25, 27, 28(3), 30, 31, 32, 35, 37, 38, 39, and 42(2).

In Yolo County (PM 0 through PM 10), the characteristics of this portion of the corridor are very uniform throughout with flat terrain. There are fairly wide median widths along the majority of this portion of the corridor, with the exception of viaduct portions which contain no useable median area. No land use restrictions to lateral expansion are evident. Other notable observations include frontage roads, although they do not appear to pose a restriction to lateral expansion of the highway. Lands along this portion of the corridor consist primarily of cultivated and fallow farmlands. Viaduct portions are required due to the surrounding floodplain area. Overpasses are located at Post Miles 0 and 3.

CORRIDOR #6

Corridor #6 consists of the 151.3 kilometer portion of State Route 99 which connects the urbanized regions of Bakersfield and Fresno.

In Kern County (PM 32 through PM 57), characteristics of this portion of the corridor are fairly uniform throughout with very flat terrain. Median widths are fairly narrow with some instances of wider medians. No land use restrictions to lateral expansion are evident; some clustered land uses exist within the communities through which the corridor passes.
Other notable observations include cultivated farmlands. Railroad lines are located adjacent to the highway, although they do not appear to pose a restriction to lateral expansion of the highway. Overpasses are located at Post Miles 36, 41, 44, 47, 49, 50, 52, 54, 55, 56(2), and 57.

In Tulare County (PM 0 through PM 54), characteristics of this portion of the corridor are fairly uniform throughout with very flat terrain. Median characteristics consist of fairly wide median widths, with the exception of one segment with no useable median area from PM 34 to PM 37. Land use restrictions to lateral expansion consist of scattered rural residential and commercial land uses. Other notable observations include cultivated farmlands. Railroad lines located adjacent to the highway, as well as frontage roads and soundwalls, do not appear to pose a restriction to lateral expansion of the highway. Overpasses are located at Post Miles 0, 6(2), 7, 12(2), 13, 15, 18, 19, 20, 23, 25, 28, 29(3), 30, 32, 34, 40, 43, 48, 51, and 53.

In Fresno County (PM 0 through PM 15), characteristics of this portion of the corridor are fairly uniform throughout with very flat terrain. Median areas are fairly wide throughout. Land use restrictions to lateral expansion include some scattered rural residential and commercial land uses. Other notable observations consist of cultivated farmlands. Railroad lines located adjacent to the highway, as well as frontage roads, do not appear to pose any restrictions to lateral expansion of the highway. Overpasses are located at Post Miles 2, 4, 9, 12, and 14.

CORRIDOR #7

Corridor #7 consists of the 233.5 kilometer portion of State Route 99 which connects the urbanized regions of Fresno and Sacramento.

In Madera County (PM 0 through PM 29), characteristics of this portion of the corridor are fairly uniform throughout with very flat terrain. There are fairly wide medians for most of this portion of the corridor, with the exception of two segments with no usable median areas from PM 11 to PM 12 and from PM 22 to PM 23. Scattered land uses represent minor land use restrictions to lateral expansion. Most land uses in the vicinity of the highway are set back beyond the adjacent railroad tracks. Other notable observations include cultivated farmlands. Railroad lines located adjacent to the highway do not appear to pose a restriction to lateral expansion of the highway. Overpasses are located at Post Miles 1, 2, 3, 6, 8, 10(2), 11(2), 12, 13, 14, 16, 19, 23, 24, 26, and 28.

In Merced County (PM 0 through PM 37), characteristics of this portion of the corridor vary throughout. Terrain is very flat and median widths are fairly wide along most of this portion of the corridor, with the exception of one small segment with no usable median area from PM 9.2 to PM 9.9 and narrower medians near at-grade intersections. Land use restrictions to lateral expansion are minor and include scattered land uses. The freeway segment for this portion of the corridor, from PM 15 to PM 24, contains more land uses (including industrial uses) than the remainder of this portion. Other notable observations include cultivated farmlands. Segments from PM 0 to PM 15 and from PM 24 to PM 37 are not full-access controlled freeways; PM 0 to PM 15 contains 15 unsignalized at-grade intersections and PM 25 to PM 37 contains 13 at-grade intersections, including one signalized intersection at PM 30. In addition to at-grade intersections within these segments, many U-turn areas are located along the highway. Overpasses are located at Post Miles 13, 18, 20, 22, 30, 34, 36, and 37.

In Stanislaus County (PM 0 through PM 25), characteristics of this portion of the corridor are fairly uniform throughout with very flat terrain. Median widths are fairly wide, with some short narrow segments including one segment with no usable median area from PM 16 to PM 18. Land use restrictions to lateral expansion include many urban land uses. The beginning of this portion of the corridor consists of farmland. Other notable observations include frontage roads and soundwalls. Frontage roads do not appear to pose a restriction to lateral expansion of the highway while soundwalls appear to pose some restrictions. Overpasses are located at Post Miles 0, 2, 4, 7, 10, 11, 12, 13, 14, 15(4), 16(2), 17(2), 18, 20, 22, 23, and 24.

In San Joaquin County (PM 0 through PM 39), characteristics of this portion of the corridor are fairly uniform throughout with very flat terrain. Median widths are fairly wide, with the exception of one segment with no usable median area from PM 0 to PM 2. Land use restrictions to lateral expansion consist of numerous urban land uses. Very little farmland exists along this portion of the corridor. Other notable observations include a nearly continuous frontage road, although it does not appear to pose a restriction to lateral expansion of the highway. Some "tight" access and egress points, with no accompanying ramps, are located along this portion of the corridor. Overpasses are located at Post Miles 1, 2, 3, 5, 6, 7, 8, 9(2), 14, 16, 17(4), 18(3), 19(2), 20(2), 21(2), 22(2), 23, 24, 25, 27, 28, 29, 30(4), 31(3), 32, 33, 34, 35, 36, and 37.

In Sacramento County (PM 0 through PM 15), roadway characteristics are fairly uniform throughout with very flat terrain and fairly wide medians. No land use restrictions to lateral expansion are evident. This area is primarily rural with scattered urban land uses. Other notable observations include frontage roads and a limited number of soundwalls, although they do not appear to pose any restrictions to lateral expansion of the highway. Overpasses are located at Post Miles 1, 2(2), 3, 6, 7, 10, 13, and 15.
[This page left blank]

APPENDIX 8

DESCRIPTION OF SEGMENTS FOR U.S. 101

Segment #1: Junction 101/5 to Alameda (LA PM S0.00 through LA PM 0.76)

- Mostly three lanes with short two lane segment
- Approximately seven overpasses and four underpasses
- Includes the 101/5/10W, 101/60, and 101/10E splits, merges, and interchanges
- Very narrow median
- Four land use restrictions to the east (approximately 133 meters)
- Six land use restrictions to the west (approximately 915 meters)

Segment #2: Alameda to Grand (LA PM 0.76 through LA PM 1.32)

- Three lanes throughout
- Six overpasses and no underpasses
- Includes the 101/110 split
- Very narrow median
- One land use restriction to the east (approximately 527 meters - depressed downtown area with retaining walls and frontage roads)
- One land use restriction to the west (approximately 620 meters - depressed downtown area with retaining walls and frontage roads)

Segment #3: Grand to Edgeware (LA PM 1.32 through LA PM 2.07)

- Three lanes southbound throughout; mostly three lanes northbound with very short four lane segment
- One overpass and three underpasses
- Includes the 101/110 interchange
- Very narrow median
- No land use restrictions to the east
- One land use restriction to the west (approximately 248 meters)

Segment #4: Edgeware to Virgil (LA PM 2.07 through LA PM 4.08)

- Four lanes throughout
- Four overpasses and five underpasses
- Very narrow median
- Three land use restrictions to the east (approximately 155 meters)
- Two land use restrictions to the west (approximately 124 meters)

Segment #5: Virgil to Junction 101/134 (LA PM 4.08 through LA PM 11.47)

- Four and five lane segments
- Approximately 13 overpasses and 14 underpasses
- Includes the 101/170 split
- Narrow median with the exception of several short segments with wide medians
- Nine land use restrictions to the east (approximately 713 meters)
- 12 land use restrictions to the west (approximately 2031 meters)

Segment #6: Junction 101/134 to Colfax (LA PM 11.47 through LA PM 12.00)

- Three, four, and five lane segments
- Approximately two overpasses and three underpasses
- Includes the 101/170/134 interchange
- Wide median
- No land use restrictions

Segment #7: Colfax to Van Nuys (LA PM 12.00 through LA PM 15.91)

- Five lanes throughout
- No overpasses and eight underpasses
- Very narrow median
- One land use restriction to the east (approximately 217 meters)
- One land use restriction to the west (approximately 31 meters)

Segment #8: Van Nuys to Haskell (LA PM 15.91 through LA PM 17.50)

- Three, four, and five lane segments
- No overpasses and approximately four underpasses
- Includes the 101/405 splits, merges, and interchange
- Very narrow and wide median areas
- One land use restriction to the east (approximately 279 meters)
- One land use restriction to the west (approximately 155 meters)

Segment #9: Haskell to Valley Circle/Mulholland (LA PM 17.50 through LA PM 27.36)

- Four and five lane segments
- One overpass and 17 underpasses
- Very narrow median
- One land use restriction to the east (approximately 124 meters)
- Six land use restrictions to the west (approximately 1225 meters)

Segment #10: Valley Circle/Mulholland to Las Virgenes (LA PM 27.36 through LA PM 31.05)

- Four lanes throughout
- Four overpasses and no underpasses

- Narrow median
- One land use restriction to the east (approximately 62 meters)
- One land use restriction to the west (approximately 62 meters)

APPENDIX 9

RATING OF AUTOMATED HIGHWAY DESIGN OPTIONS: U.S. 101 (LA PM S0.00 THROUGH LA PM 31.05)

	SEGMENT NUMBER*									
Design Option	1	2	3	4	5	6	7	8	9	10
At-Grade:										
Lane Conversion	1	1	1	**3**	**3**	1	**3**	1	**3**	**3**
Median	1	1	1	1	1	1	1	1	1	1
Median/Shoulder	**2**	1	**2**	2	2	1	2	**3**	1	3
Shoulders	2	1	2	2	2	1	2	3	2	3
Above-Grade:										
Median	2	**3**	2	2	2	1	2	2	2	3
Shoulders	2	1	2	2	2	**2**	2	3	2	3
Below-Grade:										
Tunnel	1	2	1	1	1	2	1	1	1	1

*Refer to appendix 6 for description of individual segments

Rating Scale: 1 = Not Feasible
2 = Possible, But Difficult

Note: Numbers in **boldface** represent the most desirable design option for the subject segment.

3 = Relatively Easy

A rating scale of 1 to 3 was used in evaluating the feasibility of each design option by segment. The rating scale used was follows: 1 = not feasible; 2 = possible, but difficult; 3 = relatively easy. An interpretation of the design option rating scale used in this analysis is as follows:

Design Option	Rating	Interpretation of Rating
<u>At-Grade</u>		
Lane Conversion:	1	The segment does not contain at least four through lanes in each direction for its entire length.
	2	Not applicable.
	3	The segment contains at least four through lanes in each direction for its entire length.
Median:	1	The segment does not contain sufficient median space throughout its entire length to accommodate at least two automated traffic lanes and a median barrier.
	2	Not applicable.
	3	The segment contains sufficient median space throughout its entire length to accommodate at least two automated traffic lanes and a median barrier.
Median/ Shoulders:	1	The segment does not contain a sufficient combination of median space and space between the outside shoulders and ROW boundaries throughout its entire length to accommodate at least two automated traffic lanes and a median barrier.
	2	In general, the segment does contain a sufficient combination of median space and space between the outside shoulders and ROW boundaries throughout its entire length to accommodate at least two automated traffic lanes and a median barrier. However, this rating indicates the presence of significant land use restrictions to lateral expansion.
	3	In general, the segment does contain a sufficient combination of median space and space between the outside shoulders and ROW boundaries throughout its entire length to accommodate at least two automated traffic lanes and a median barrier. This rating indicates that land use restrictions to lateral expansion are either nil or very minimal.
Shoulders:	1	The segment does not contain sufficient space between the outside shoulders and ROW boundaries throughout its entire length to accommodate at least two automated traffic lanes.

2 In general, the segment contains sufficient space between the outside shoulders and ROW boundaries throughout its entire length to accommodate at least two automated traffic lanes. However, this rating indicates the presence of significant land use restrictions to lateral expansion.

3 In general, the segment contains sufficient space between the outside shoulders and ROW boundaries throughout its entire length to accommodate at least two automated traffic lanes. This rating indicates land use restrictions to lateral expansion are either nil or very minimal.

<u>Above-Grade</u>

Median: 1 An above-grade automated highway facility could not be constructed in the median of the segment due to a lack of available space which is necessary to accommodate the structural elements of the facility.

2 An above-grade automated highway facility could be constructed in the median of the segment. However, the segment contains at least one underpass which would present difficulties in constructing an above-grade facility.

3 An above-grade automated highway facility could be constructed in the median of the segment. Furthermore, this rating indicates that the segment contains no underpasses.

Shoulders: 1 An above-grade automated highway facility could not be constructed in the space between the outside shoulders and ROW boundaries of the segment due to a lack of available space which is necessary to accommodate the structural elements of the facility.

2 An above-grade automated highway facility could be constructed in the space between the outside shoulders and ROW boundaries of the segment. However, this rating indicates the presence of significant land use restrictions to lateral expansion.

3 An above-grade automated highway facility could be constructed in the space between the outside shoulders and ROW boundaries of the segment. Furthermore, this rating indicates land use restrictions to lateral expansion are either nil or very minimal.

<u>Below-Grade</u>

Tunnel: 1 The length of the segment is too long to consider the use of tunnels to accommodate automated traffic lanes.

2 The length of the segment is appropriate to consider the use of tunnels to accommodate automated traffic lanes. However, the segment, or a significant portion of the segment, is depressed.

3 The segment is appropriate to consider the use of tunnels to accommodate automated traffic lanes. Furthermore, no significant portion of the segment is depressed.

REFERENCES

(1) California Department of Transportation, *1992 Route Segment Report*, August 1993.

(2) California Department of Transportation, *Highway Congestion Reports*, 1992.

(3) JHK & Associates, *SMART Corridor Statewide Study, Final Report*, June 1990.

(4) Cottrell, W.D. "Measurement of the Extent and Duration of Freeway Congestion in Urbanized Areas", *Compendium of Technical Papers - ITE 61st Annual Meeting*, Institute of Transportation Engineers, 1991.

(5) California Department of Transportation, "1992 California State Highway Log" (Districts 3, 4, 7, 8, 11, and 12).

(6) Air Pollution Control District County of San Diego, "1992 Annual Report", 1993.

(7) Hitchcock, A. *Layout, Design, and Operation of a Safe Automated Highway System*, UCB-ITS-PRR-94-17, March 1994.

(8) California Department of Transportation, *Traffic Manual*, "Chapter 7-Guardrail, Median Barriers, Crash Cushions",