

California AHMCT Research Center
University of California at Davis
California Department of Transportation

**SURVEY QUESTIONNAIRE:
CONSTRUCTION AND MAINTENANCE
REQUIREMENTS FOR AN AHS**

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ABSTRACT

Conventional construction and maintenance methods and procedures will not be able to support the development of an Automated Highway System (AHS). With the increasing traffic and limited capacity of the existing infrastructure, conventional construction and maintenance operations will severely impact the existing traffic problems of today unless operations are improved, developed and advanced in parallel to the development of an AHS. Survey questionnaires were prepared and distributed to selected transportation experts requesting qualitative assessments of the impact considerations that need to be addressed in terms of construction, design, maintenance, new technology, pavement, structures and traffic operations. The survey responses are summarized and discussed.

EXECUTIVE SUMMARY

The California Department of Transportation and the University of California, Davis are participating in a Precursor System Analysis that will identify and address concerns and requirements for the automation of construction and maintenance operations in an Automated Highway System (AHS). This preliminary report summarizes the results from a survey questionnaire that was developed and distributed to identify specific concerns related to the construction, maintenance and operation of an AHS. A total of thirty-one surveys were distributed to transportation experts to determine considerations, assessments and impacts for the development, implementation and deployment of an AHS.

Seven different survey questionnaires were developed to address specific areas of expertise including design, construction, maintenance, pavement, and operations. In addition, a generalized survey questionnaire was listed on the American Association of State Highway and Transportation Organization (AASHTO) Hotline to electronically acknowledge and invite participation from transportation experts residing in other states.

Thirty-one questionnaires were distributed to transportation experts that are employed by transportation organizations. Subsequent surveys will target transportation experts from academia and the private sector.

Assumptions were made based on applicable technology that is currently being prototyped and field tested and that have demonstrated technology feasibility. These assumptions were provided in each survey questionnaire.

Conventional methods of performing construction and maintenance operations need to be addressed in parallel to the development of an AHS. The result from the survey responses indicates that the majority of the questionnaire participants confirms the need to use automation and robotics to advance construction and maintenance operations to safely and efficiently meet the demands of the traveling public.

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COMMON CONVERSION FACTORS TO METRIC UNITS

CLASS	MULTIPLY	BY:	TO GET:
Area	acre acre ft ² yd ² mi ²	4047.0 0.4047 0.0929 0.8361 2.590	m ² ha (10,000 m ²) m ² m ² km ²
Length	ft in mi yd	0.3048 * 25.4 1.6093 0.9144 *	m mm km m
Volume	ft ³ gal fl oz yd ³ acre ft	0.0283 3.785 29.574 0.7646 1233.49	m ³ L ** mL ** m ³ m ³
Mass	oz lb kip (1,000 lb) short ton (2,000 lb) short ton	28.35 0.4536 0.4536 907.2 0.9072	g kg tonne (1000 kg) kg tonne (1000 kg)
Density	lb/yd ³ lb/ft ³	0.5933 16.0185	kg/m ³ kg/m ³
Pressure	psi ksi lb/ft ²	9894.7 6.8947 46.88	Pa MPa (N/mm ²) Pa
Velocity	ft/s mi/h mi/h	0.3048 0.4470 1.6093	m/s m/s km/h
Light	footcandle (lumen/ft ²)	10.764	lux (lx) (lumen/m ²)
Temperature	°F	$t_c = (t_f - 32)/1.8$ °c °f	°C

* Exact

** Both "L" and "l" may be used for liter. However, "L" is preferred so as not to be confused with the numeral "1".

DISCLAIMER

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Center, within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of New Technology and Materials Research at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the STATE OF CALIFORNIA or the FEDERAL HIGHWAY ADMINISTRATION and the UNIVERSITY OF CALIFORNIA. This report does not constitute a standard, specification or regulation.

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CHAPTER 1: SURVEY QUESTIONNAIRES

INTRODUCTION

An Automated Highway System (AHS) development program is currently being supported by the United States Department of Transportation. The multi-effort AHS development program is structured in three phases: Analysis Phase, Systems Definition Phase and Operational Evaluation Phase. The California Department of Transportation (Caltrans) and the University of California, Davis (UC Davis) are participating in a Precursor Systems Analysis that will identify and address concerns and requirements for the automation of construction and maintenance operations in an AHS.

Survey questionnaires were developed and distributed to identify specific concerns related to the construction, maintenance and operation of an AHS. Solicited responses from a selected host of transportation experts have provided additional insight to considerations and potential impacts due to the implementation and deployment of an AHS.

The analysis and evaluation based on the information provided will assist Caltrans and the Federal Highway Administration (FHWA) in addressing potential advantages/disadvantages to construction, maintenance and operations that may be imposed with an AHS.

Background

The Advanced Highway Maintenance and Construction Technology (AHMCT) program was initiated in 1989. Caltrans, in partnership with UC Davis, developed and currently manages the AHMCT Center to address the needs of automating maintenance and construction equipment to accommodate current and future transportation systems. Research efforts are directed at meeting the needs of the traveling public while maintaining a safe working environment for maintenance and construction employees.

The goals of the AHMCT program are to decrease hazardous exposure to employees, minimize delays to the traveling public, increase efficiency of construction and maintenance operations, increase reliability of the highway infrastructure and increase economic benefits in special areas such as roadway, roadside and structure construction and maintenance as well as to increase worker safety.

As stated in the U.S. DOT IVHS Strategic Plan - Report to Congress, December 18, 1992, "The Secretary (of Transportation) shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed. Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles."⁽¹⁾

Achieving this long term goal will require the development of safety advisory and driver assistance products for near term deployment that will serve as building blocks for AHS, provide immediate safety benefits and capitalize on investments of public and private sector funds in the program.

The AHMCT program primarily researches innovative alternatives using robotics and automation to safely and efficiently advance conventional construction and maintenance operations. Realistically, conventional construction and maintenance methods and procedures will not be able to support the development of an AHS. With the increasing traffic and limited capacity of the existing infrastructure, conventional construction and maintenance operations will severely impact the existing traffic problems unless operations are improved, developed and advanced in parallel to the development of an AHS.

For the purpose of this study, an operational AHS is assumed to have the following characteristics:

- Evolves from conventional highways (beginning in selected corridors and routes).
- Provides fully automated “hands-off” operation with improved vehicle performance in terms of increased safety, efficiency and ride quality.
- Allows vehicles equipped with new technologies to operate in both urban and rural areas on highways that are instrumented or on highways that are *not* instrumented.

Although the long term goal of the AHS development program is to successfully deploy an automated highway system, initial assessments are imperative to determine the impact of various system configurations on conventional construction, maintenance and traffic operations.

Purpose

This preliminary report is prepared under contract with the Federal Highway Administration to survey and evaluate the impact that an automated highway system will have on construction and maintenance operations. Assessing the need for automated or robotic equipment to support these operations is critical in the development of an AHS infrastructure and implementation. Although many aspects of an AHS are being considered, construction and maintenance operations will have a direct impact to the development and deployment of an AHS and will need to initially be included in the overall AHS vision.

Scope

It is important to assess the impact of the construction and maintenance operations when evaluating the evolution of the conventional transportation system to a new generation transportation system. The Precursor System Analysis is a feasibility study to determine how the construction and maintenance operations will be affected by the architecture of various system configurations. Potential impacts will be fully discussed in this preliminary report.

Study Overview

Seven independent survey questionnaires were developed and distributed in this study. The questionnaires were prepared specifically for transportation experts in the following areas:

- Design.
- Construction.
- Maintenance.
- New Technology.
- Pavement.
- Structures.
- Traffic Operations.

A general type survey questionnaire was not used because questions were directed to a specific area of expertise and were not applicable in all instances. However, where applicable, standard questions were included to obtain a general consensus.

See appendices A through C for a sample of survey questionnaire, a cumulative listing of survey questions and a summary of individual survey responses, respectively.

CHAPTER 2: DISCUSSION

APPROACH/METHODOLOGY

Analysis and understanding of the concerns related to the applicability of recent advances in robotic and design technologies for AHS construction and maintenance is a critical component in assessing the requirements for an AHS infrastructure. Seven independent survey questionnaires were prepared and distributed to transportation experts to determine and address concerns in specialized transportation areas such as Design, Construction, Maintenance, New Technology, Pavement, Structure and Traffic Operations. Survey responses provided additional information and perspectives on the need to automate maintenance and construction operations in an AHS environment, concerns of an AHS, resolutions or alternatives to solve specific problems, identification of possible maintenance and construction tasks that have the potential of being automated and identification of possible test sites to facilitate field testing and demonstrations.

Survey Questionnaires

Survey questionnaires were prepared and distributed to selected transportation experts residing primarily in California. Survey questionnaires were distributed to highly specialized transportation experts working in specific areas such as highway construction and maintenance, traffic management, structure design and construction, highway design, pavement engineering, systems engineering, advanced transportation information and management, research, safety, traffic improvement and transportation planning.

A total of thirty-one survey questionnaires were distributed. A video tape, entitled, "IVHS Technologies for Transportation", originally developed by the U.S. Department of Transportation, was included in a distribution package to provide information on a conceptual architecture and operation of an AHS. Each survey questionnaire was developed based on the model of an AHS as illustrated in the video tape. Also, a generalized survey questionnaire was listed on the American Association of State Highway and Transportation Organization (AASHTO) Hotline to electronically solicit responses from thirty-nine other states. See appendices B and C for a listing of the questions and responses, respectively.

Survey questionnaires were sent throughout the state of California. Caltrans consists of twelve districts. These districts are located in urban and rural areas and experience variable weather conditions such as rain, snow and fog. The selected group of transportation experts were chosen based on specialized areas of expertise. This part of the study concentrated on responses from transportation experts that are employed with a transportation organization. Thus, the selection of transportation experts are primarily employed by Caltrans; however, other transportation experts from other state Department of Transportations also participated in this study.

Table 1 illustrates that a total of thirty-one survey questionnaires were distributed to selected transportation experts, and to date, a total of twenty-nine survey questionnaires have been received. The survey questionnaires were distributed to upper management, and in some instances, individual survey questionnaires were further distributed to other transportation experts within the same working group.

Currently, the total response rate is 71%.¹ In addition, the states of Arkansas, Iowa, Nebraska and Texas account for a response rate of 10% from other states.

Table 1. Representation of Surveys Distributed and Surveys Received

Areas	Questionnaires Distributed	Questionnaire Received	Response Rate
Construction	1	1	100%
Design	1	1 (7) ²	100%
Maintenance	13	8 (10) ²	62%
New Technology	11	8	73%
Pavement	1	1	100%
Structures	3	3	100%
Traffic Operations	1	0	0%
TOTAL	31	22 (29) ²	71%
Other States	39	4	10%

Assumptions

Assumptions were made based on applicable technology that is currently being prototyped and field tested and that have demonstrated technology feasibility. These assumptions were provided in each survey questionnaire, with the exception of the New Technology questionnaire and are as follows:

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.

Note:

- The magnetic nails are 25.4 mm in diameter and 10.2 cm in length, flush with the pavement surface and placed at 91.4 cm intervals.^(2,3)
- Passive/Active wires can be slot cut into the middle of the pavement similar to the installation of detector loops.⁽⁴⁾

- The implementation of vehicle guidance and control can potentially increase highway capacity.⁽⁵⁾ For example, vehicle longitudinal control can reduce operating headways (distance between vehicles), and vehicle lateral control has the potential to reduce conventional lane widths.

¹ This calculation was based on the actual number of survey questionnaires distributed and received, not including the number of survey questionnaires received from further distribution within a working group.

² The number in parenthesis represents the total number of survey questionnaires received including the number of survey questionnaires received from further distribution within a working group.

- Vehicle operational speed may approach 128.7 km/h.

An AHS is envisioned to consist of some level of roadway intelligence for vehicle guidance and control. Great emphasis in developing various sensing technologies have been ongoing; however, the primary sensing technology has not yet been determined. Thus, magnetic nails, active wire or passive wire that may be embedded in the highway are presented as examples of vehicle guidance and control. Also, specifications were provided for the installation of potential reference sources that may possibly impact the existing highway or should be taken in consideration for any new construction of an AHS.

Another assumption made was that advanced vehicle guidance and control has the potential to increase overall highway capacity. Vehicle longitudinal control using radar sensors is currently being developed to control vehicle headways (front to front). Highway capacity may be increased due to the increased volume of vehicles that may occupy a single highway lane. The relationship between average spacing and average headway in a traffic stream is dependent on speed.⁽⁶⁾ Thus, the average headway is 3 seconds per vehicle, traveling at a speed of 88 km/h. However, with advanced vehicle longitudinal control, the headway could potentially be reduced to 0.04 seconds per vehicle, traveling at a speed of 88 km/h. Thus, within a highway lane, the highway capacity could increase substantially. Also, with advanced vehicle lateral guidance using a reference system, highway capacity may be increased due to reduced lane widths. With the width reduction of each conventional highway lane, additional highway lanes may provide increased highway capacity without requiring additional right of way or new construction.

Conventional highway speeds range from 88.5 km/h to 104.6 km/h. An AHS is assumed to have provisions to safely and efficiently operate vehicles at estimated speeds up to 128.7 km/h. This assumption was made to inform the survey questionnaire participants that an AHS is assumed to operate at higher vehicle operational speeds.

System Configurations/Scenarios

Although the standardized system configuration for an AHS has not been established, system configurations were developed and included, where applicable, in the seven independent survey questionnaires. A system configuration describing specific scenarios that related to the survey questions was provided as resource information. Additional information that was not pertinent to the survey questions was not provided.

Most of the survey questionnaires included a system configuration that was defined as follows:

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

Scenario 1:

- Only light weight, automated vehicles operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- Designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Scenario 2:

- All (light weight and heavy weight), automated vehicles operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- Designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.
- The implementation of vehicle guidance and control can potentially increase highway capacity. For example, vehicle longitudinal control can reduce operating headway (distance between vehicles), and vehicle lateral control has the potential to reduce conventional lane widths.
- Vehicle operational speed may approach 128.7 km/h.

Scenario 1 describes an AHS that is developed with new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes. Any new construction must remain within a specified right of way and must also comply with environmental standards and requirements. In addition, designated automated highway lanes are segregated by barriers that physically separate non-automated lanes from automated lanes. Separating automated lanes and non-automated lanes with a physical barrier is assumed to be the best alternative to prevent non-automated vehicles from entering the automated lanes, thus avoiding the potential of mixed flow vehicle operations. Also, only light weight, automated vehicles will be operated on the designated automated lanes.

Scenario 2 describes a similar AHS; however, all types of vehicles will be operated on the designated automated lanes. Vehicle types include both light weight and heavy weight vehicles.

These two scenarios were included in the Construction, Design, Maintenance, Traffic Operations and Pavement survey questionnaires. The type of vehicles that will be operated on the automated highway lanes will have a definite impact on the infrastructure and pavement design, construction, maintenance and operation of an AHS.

The scenario included in the Structures survey questionnaire is as follows:

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

- Only light weight vehicles operate on elevated structures that may be located above the median, outer separation or conventional highway lanes. The elevated structure consists of two opposing highway lanes that are physically separated by a barrier with breakdown lanes available for vehicle failure and emergency response.

This scenario describes an AHS that is developed with new elevated structures that may be located above the median, outer separation or conventional highway lanes. With the limited right of way available for new construction, alternatives must be considered to efficiently use the existing transportation system right of way. Thus, a viable alternative is to design and construct new elevated structures to improve traffic flow and to maximize the use of available right of way. The elevated structures are envisioned to consist of two opposing highway lanes that are

physically separated by a barrier with breakdown lanes available for vehicle failure and emergency response. Breakdown lanes will be necessary for emergency teams to expeditiously access areas where incidents occur due to vehicle failure or malfunction. Only light weight vehicles will be operated on these elevated structures to reduce the cost of constructing a new highway lane.

A scenario was not included in the New Technology survey questionnaire. Generalized questions were developed to assess the need for advancing construction and maintenance operations in parallel to the advancement of the conventional transportation system. Survey questionnaire participants who have the expertise in working with New Technology are familiar with potential scenarios and were not restricted to any one scenario in particular.

CHAPTER 3: SUMMARY

Following is a brief synopsis of responses covering several frequently asked questions. These questions differ somewhat from the questions asked to the survey questionnaire participants, but all components of answers were obtained directly from the survey responses. The authors have taken some liberty in rewriting responses in order to either shorten the response or ease transition from one response to another. A blending of responses from different questionnaires has also occurred to produce answers to these frequently asked questions. Actual responses received from the survey questionnaires can be referenced in appendix C.

Assuming larger volumes of traffic and higher speeds with an AHS, will maintenance operations need to be automated to meet the needs and demands of the traveling public?

- Any moves in the direction of an AHS need to consider the maintainability of the system. This should be a necessary consideration of the System Definition and System Architecture Phases of the AHS program. A properly designed AHS should enhance maintainability.
- New levels of liability might evolve with an AHS. This could be a "show stopper". Maintenance negligence is currently a primary claim on a large proportion of transportation department's lawsuits. How to maintain and how reliable and safe the system can be will be extremely important. Maintenance issues need to be surfaced early.
- In the early days of AHS deployment it appears that there will be a minimum number of lanes available. Any slow down or blockage of the AHS lanes will create major problems which will be highlighted by the media and opponents of AHS as showing that AHS won't work. It is imperative that maintenance operations on an AHS infrastructure be automated from the beginning to reduce lane closures and work areas to an absolute minimum.
- A very important issue will be the fail-safe operation of the infrastructure electronics including communications beacons, guidance equipment and other equipment related to vehicle control. The primary issue is to establish and maintain up time and operational status. Maintenance functions will have to be performed faster; restoring the integrity of a sensor for example could be performed at AHS speed without traffic interruption (reduction of speed may be necessary). With the AHS traffic at such close headways and such high volumes, a shutdown of the infrastructure electronics has the potential to cause or aggravate a major accident.
- Any work that must be done should be designed to be completed at the prevailing speed of traffic. This would have little impact on the highway capacity and should not cause unnecessary delays to motorists. This would also require that maintenance operations be conducted without workers on foot. This would have the additional benefit of significantly reducing risks to highway workers from errant vehicles.
- Night work is identified as an alternative mechanism for performing routine maintenance. Concerns of safety increase, with night work justifying automated operation where possible.

- While most maintenance functions will need to be automated to meet the demands of an AHS, safety and economics have to be carefully considered when evaluating automation of maintenance functions.

Can maintenance operations take advantage of AHS?

- There is a host of possible uses of AHS technology in construction and maintenance. An example of this includes the use of guidance and control technology to guide maintenance vehicles thus increasing the speed and efficiency of the operation. The operation of unmanned equipment could be controlled from a central traffic management center eliminating exposure to maintenance workers and subsequently eliminating shadow operations. Suggested examples include sweeping operations, paint striping, pavement overlays, sealing, and herbicide spray operations. One respondent suggested that robotic equipment designed and developed as part of the Strategic Highway Research Program (SHRP) could use the AHS guidance and control systems.
- Vehicles operated by the traveling public can be used as probes relaying real-time information on potential maintenance problems. One suggested scenario of this would be the secondary use of sensor systems on the vehicle such as a vision system. Information as to location and extent of damage to the infrastructure could be relayed in real-time for immediate dispatch of a maintenance vehicle. The AHS infrastructure could then guide maintenance personnel to the exact location of the problem. The infrastructure could slow the traffic in the area to the speed necessary for the maintenance vehicle to make the repair "on the fly" using automated maintenance functions such as robotics.
- The AHS infrastructure will be able to provide a wealth of information to construction and maintenance operations related to traffic, including such things as volume, speed, location of bottlenecks, and sudden slow downs.
- An important safety benefit appears to be the automatic redirection of traffic around the maintenance workzone (lanes programmed out of operation automatically) thus eliminating the possibility of errant drivers. Furthermore, sensors may be able to stop vehicles from inadvertently entering a maintenance workzone.
- Finally, feedback from the vehicle guidance and control system could be used for maintenance vehicle positioning, facilitating the tracking of active construction and maintenance operations. Real-time information regarding the exact location of moving lane closures could also be automatically broadcast to the traveling public.

What types of tasks could be automated to facilitate the construction and maintenance of an AHS?

- An AHS will require more precise construction methods and would definitely require an automated construction process. An example of this includes the development of equipment to automatically and accurately position and place guidance and control reference sensors and roadside communication equipment needed for an AHS. Additionally, special diagnostic equipment

could evaluate the AHS systems performance at prevailing speed and make repairs without exposing workers to traffic.

- There is a high likelihood that maintenance vehicles could be operated remotely or in an autonomous mode if it used the AHS. Incorporation of an AHS type guidance system into maintenance vehicles will enhance maintenance activities allowing maintenance personnel to attend to activities other than guiding the vehicle. Types of tasks that will benefit from automatic guidance include sweeping, crack sealing and filling, patching operations, resurfacing, grinding, electric and electronics repair, snow removal, litter gathering, lane marking such as striping and placement of pavement markers, landscape maintenance, watering, and garbage removal. Automatic self-contained barrier vehicles could also be used rather than traffic cones and signs.
- A vehicle with accurate positioning capabilities could also be used to survey maintenance needs by post mile. Video equipment and sensors could be used to monitor the system to ensure proper operation or immediate awareness of a problem.

How would the construction and maintenance of an automated highway lane (sub-base, pavement, etc.) compare with conventional procedures?

- Survey results indicate that there would be very little difference in the design and construction of an automated highway lane short of the installation of the selected reference source. On the other hand, there is considerable uncertainty over the maintenance of references and pavement embedded with references. Respondents suggested that substantial increases in labor and material costs would be incurred due to the extra care that would be taken so as not to damage or interfere with the sensors, and the repair and replacement of embedded references (citing the high failure rates of conventional subsurface loop detectors). There is also concern over the cost of replacing subsurface or flush mounted references during spall and crack repairs, pothole filling, pavement rehabilitation, and PCC slab replacement. Additionally, questions arise related to field strength degradation following thin blanket overlays, chip seals and fog seals; will the reference need to be raised following one of these operations?
- It appears that there would be no detrimental effect on the pavement due to the installation of the wire references assuming shallow placement in the pavement (12.7 mm to 19.1 mm). Additionally, Asphalt Concrete (AC) may not be a suitable host for these references due to its flexibility and corresponding reference failures, whereas a "maintenance free" structural section such as fully reinforced concrete would provide the needed rigidity.
- Suggestions to remedy these potential problems include the placement of all guidance equipment in conduit or a raceways between the two vehicle wheel tracks or mounted in the barrier system separating lanes. This would result in reduced damage to conductors due to pavement cracking and movement while improving access for repairs.
- Many respondents suggested that heavy truck traffic would affect/degrade the performance of the pavement and corresponding reference system.

What about structures?

- Conflicts arise when considering the installation of reference sources in elevated structures. Reinforcing steel usually has a 38.1 mm to 50.8 mm cover of concrete while the magnetic nails has an assumed length of 4 inches. Corrosion acceleration due to stray current would also need to be addressed. Design and construction of the structure should provide additional non-metallic conduits and pull boxes so that the system is capable of upgrades as the technology becomes available. When feasible, remote means of transmitting power (like microwave) should be considered.

Would rutting or channelization of pavement due to lateral guidance of vehicles be of concern?

- The only effect on PCC pavement anticipated would be the acceleration of rut development were tire chains are used. On AC pavements, significant acceleration of rut development will occur. Caltrans completed an initial effort to study this issue in early 1994. Results indicate an increase in rut depth of approximately 30% to 50% (for the two temperatures studied) when wandering traffic was channelized. This is of paramount concern due to safety implications associated with the ponding of water in ruts. Materials are available to provide increased rutting resistance including stone mastic asphalt (SMA) and rubber modified AC. Solutions also include varying the placement of the vehicle sensor so that vehicle tracking is different for each type vehicle.

What about automatic installation and specialized maintenance procedures for inspection of the reference sources?

- Respondents see no significant problems developing automatic equipment or modifying pavers to embed reference sources in AC or PCC during or immediately after placement in the pavement. General consensus also indicated the need to develop automatic equipment to inspect the reference sources at prevailing speeds in order to reduce labor requirements, exposure to traffic and reduce traffic accidents as a result of reference source malfunction.

What about maintaining a lane with reduced width?

- Special maintenance vehicles will need to be developed depending on the degree of width reduction. This is especially important if one considers snow and ice removal. Current maintenance vehicles require a minimum lane width of 3.35 m in order to operate. Special vehicles might only be used in these special lanes and they may not be cost effective unless they are used on a daily basis. These vehicles could be designed with robotics in mind eliminating the need for operator workspace on the pavement.
- In terms of construction, many pieces of equipment now are adjustable down to 2.4 m widths. If demands are high and the economics are there, industry will adapt.

Could an AHS lane be delineated differently to accommodate its use as a reference system?

- Physically separated lanes may eliminate the need for pavement markings or change the placement of the markings.
- Yes. Delineation is merely a way to provide visual guidance for motorists. There is some concern that the reference line delineates a breakdown lane or "safety zone" and what implications elimination of this line would have on safety. Also, transition from an automated to a non-automated will need to be considered. Education of the drivers would be of paramount concern if this was to occur.

What construction and maintenance problems might surface as a result of an AHS?

- New levels of liability due to construction and maintenance practices.
- Channelization or rutting of pavement will be an issue with the use of lateral guidance, especially with heavy vehicles.
- Snow pileup within the confines of the separating barriers will pose a safety hazard in those regions.
- The installation of AHS technology in the pavement will increase the complexity of construction and maintenance procedures, labor requirements and costs.
- Employees will have to be more technically qualified to maintain the system. This will come from increased training and/or the hiring of a higher skilled workforce.
- Specialized instruments and equipment will need to be developed to keep this system in operation at a desired level.

Will special lane closures be required for an AHS lane?

- It might be possible to use a portable temporary strip of sensors to divert vehicles to adjacent lanes.
- Possible options include automated lane closures or automatic diversion of vehicles to other automated lanes or merging with non automated traffic. At a minimum, information regarding lane closures will be broadcast to vehicles.

Would it be feasible to construct an elevated structure using prefabricated sections and could automated machinery be used for the assembly of the sections?

- It would be feasible to construct an elevated structure using lightweight, prefabricated girders with a lightweight concrete deck or lightweight composite deck. Prefabricated columns could and should also be used on a structure of this sort. There are unresolved questions about design parameters such as modulus of elasticity, long term creep characteristics, and general performance problems with light weight concrete.
- Automated assembly of precast members has been used but is not normally considered cost effective unless site conditions create high false work costs.

What about the separation of heavy vehicles from standard passenger type vehicles?

- Research done on this subject indicate that the elimination of heavy vehicles would result in a significant service life extension for existing pavements. It would also significantly reduce the cost of future new construction if designed for lightweight vehicles only.
- A lighter, less conservative design would be required and would affect the weight of the structure which would reduce seismic loading, and the lighter live loading would permit smaller structure depths which in turn would reduce the wind loading on the structure. Less dead load and less live loads with less impact coupled with the reduced seismic and wind loading will reduce the necessary column and footing designs. The cost of such a structure would spiral downward, and the cost of construction would be reduced. Maintenance costs would be reduced not having the heavy truck loading to contend with. All in all, a much more cost-effective structure could be provided.
- Special lightweight maintenance vehicles would need to be developed to travel on this lightweight structure. In addition, one needs to consider the encroachment into the recovery area currently used for normal vehicles if this structure is to be placed in the center median of an existing transportation facility.

Could the AHS be used to facilitate emergency response?

- Yes. The AHS could be used to automatically close lanes and control emergency response equipment. Safe degradation, clear path for emergency response team, automatic incident location are all possible with an AHS.
- IVHS technology, including AHS as a whole, is expected to improve safety through minimizing human error, new control systems, preventing or reducing the severity of injuries or accidents, and enhance traveler security in all transportation modes. It could further improve emergency response through reducing demand on emergency services and real response time. AHS could provide, along with IVHS user services, real-time communication from a particular vehicle, provide vehicle location, initiate automatic emergency notification, and provide in vehicle component monitoring.
- Emergency extrication of vehicles from an AHS with minimal interruption to AHS flows is possible.
- Maintenance, operations, law enforcement, and emergency medical vehicles and personnel could use the AHS infrastructure to locate emergencies. The disabled vehicle, or another vehicle nearby will be able to notify the central or local computer where the problem is located, and likely some detail on the nature of the problem. This information can be relayed to the traffic management center and to the maintenance dispatch center for rapid response.

Any ideas about a demonstration site in California?

- Figure 1 illustrates potential California AHS test sites that were identified by the questionnaire participants.

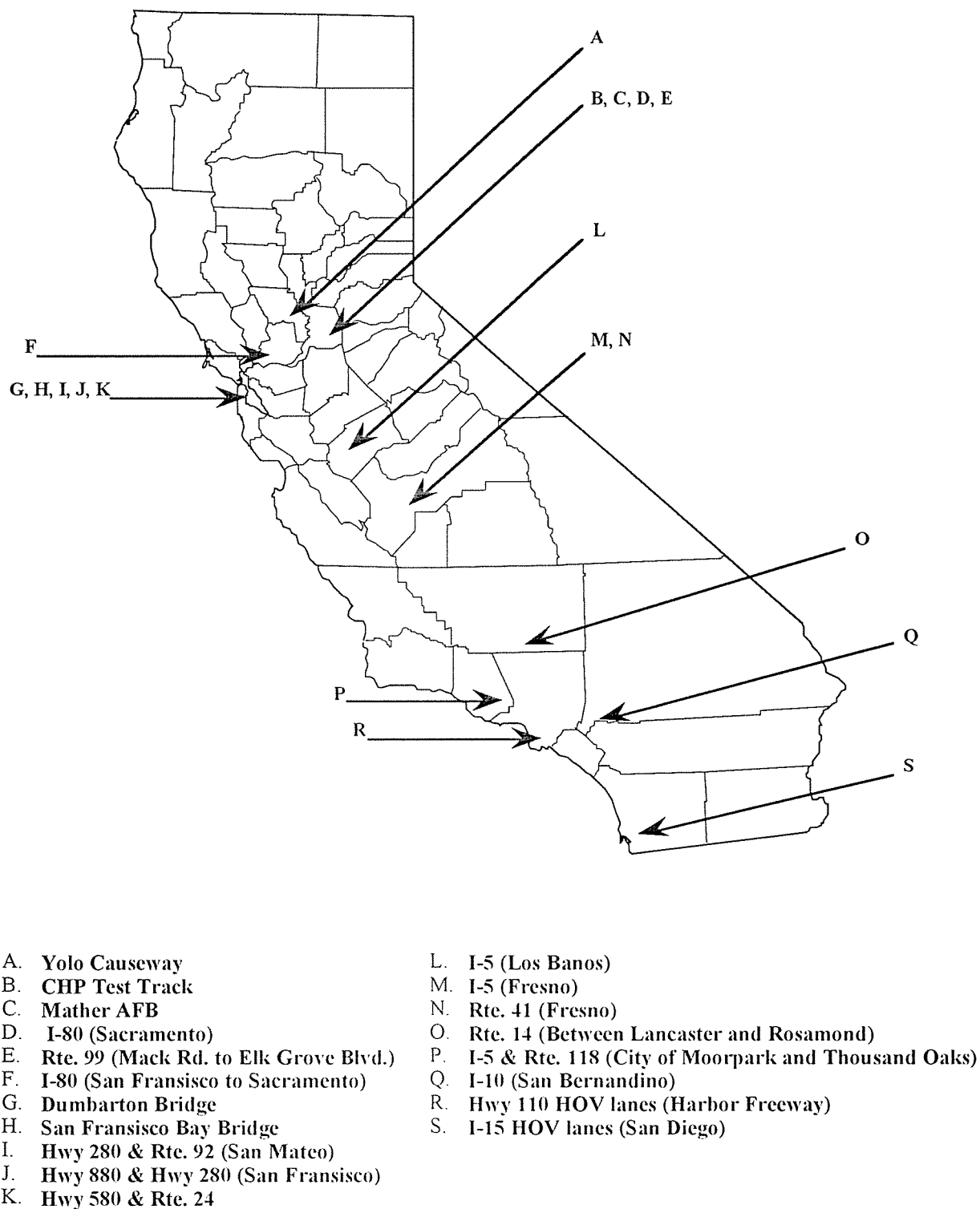


Figure 1. Potential California AHS Test Sites

CHAPTER 4: CONCLUSION

Transportation experts have been surveyed about considerations and concerns related to the construction, maintenance and operation of an AHS. Seven individual surveys were developed and distributed to address specific areas of expertise including design, construction, maintenance, pavement and operations.

Survey questions addressed concerns regarding the deployment and the maintenance of an AHS. Additionally, questions addressed specific changes from conventional construction and maintenance practices to accommodate an AHS.

The most significant result from this survey is the overwhelming confirmation from survey participants of the need to consider AHS construction and maintenance operations in parallel with the development of an AHS definition phase. More specifically, what issues of the AHS will impact future construction and maintenance? Conversely, what construction and maintenance constraints might effect the design and development of an AHS? Worth noting is the repeated concern that specialized, automated equipment will need to be developed in order to deploy and maintain an AHS.

Many respondents suggested automated equipment that would take advantage of the AHS guidance technology for accurate positioning of maintenance tasks as well as possible unmanned operation of many maintenance tasks. Other suggestions included automatic lane closure or diversion of traffic around maintenance operation, thus eliminating the need for long cone tapers and barrier vehicles.

APPENDIX A
Sample Survey Questionnaire

**A PRECURSOR SYSTEM ANALYSIS OF
AUTOMATED CONSTRUCTION AND MAINTENANCE
REQUIREMENTS FOR AUTOMATED HIGHWAY SYSTEMS (AHS)**

Questionnaire:
**Construction and Maintenance Requirements
for an Automated Highway System**

Please return this questionnaire to:

State of California, Department of Transportation
Division of New Technology, Materials and Research
Office of Advanced Vehicle and Infrastructure Development
Maintenance and Construction Technology Branch
P. O. Box 942873, MS-83
Sacramento, CA 94273

**FHWA Contract
No. DTFH61-93-C-00189**

Precursor System Analysis of AHS

Dear Questionnaire Participant:

Funds are currently available from the Federal Highway Administration (FHWA) for the research and development of an Automated Highway System (AHS) that is structured in three phases: [1] Analysis, [2] Systems Definition and [3] Operational Evaluation. The State of California, Department of Transportation (Caltrans) and the University of California at Davis (UC Davis) have secured funding to perform a Precursor Systems Analysis in the first phase of this multi-phase effort. The Precursor Systems Analysis will identify and address concerns and requirements for the automation of construction and maintenance operations in an AHS.

This questionnaire is part of a survey that is being performed to identify specific concerns related to the construction, maintenance and operation of an AHS. Responses are being solicited from a host of transportation experts that will provide additional insight to considerations and potential impacts due to the implementation and deployment of an AHS.

Find enclosed a questionnaire that is directed to your area of expertise. Information that you provide will assist Caltrans and the FHWA in addressing potential benefits/disbenefits to construction, maintenance and operations that may be imposed with an AHS. Please respond no later than February 21, 1994 to allow for evaluation, analysis and documentation of results. Thank you very much for your time and participation.

Sincerely,

Thomas West
Project Manager

Questionnaire:
**Construction and Maintenance Requirements
for An Automated Highway System**

Objectives

It is important to assess the impact of the construction and maintenance operations to accommodate the evolution of the conventional transportation system to a new generation transportation system. The Precursor System Analysis is a feasibility study to determine how the construction and maintenance operations will be affected by the architecture of various system configurations.

Responses received will help to determine the level of impact that an Automated Highway System will have on the design, construction, maintenance and operation of conventional highways.

Definition of An Automated Highway System

From the U.S. DOT IVHS Strategic Plan - Report to Congress, December 18, 1992.

AUTOMATED HIGHWAY SYSTEM

The Department has established the Automated Highway System (AHS) program to pursue the more technically challenging, longer term IVHS goal of having a fully operational vehicle-highway system that automates the driving process. This is in direct response to the *Intermodal Surface Transportation Efficiency Act of 1991*, Part B, Section 6054(b): "The Secretary (of Transportation) shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed. Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles."

Achieving this long term goal will require the development of safety advisory and driver assistance products for near term deployment that will serve as building blocks for AHS, provide immediate safety benefits and capitalize on investments of public and private sector funds in the program.

A "fully automated highway system" is assumed to have the following characteristics:

- Evolves from conventional highways (beginning in selected corridors and routes).
- Provides fully automated "hands-off" operation with improved driver performance in terms of increased safety, efficiency and ride quality.
- Allows vehicles equipped with new technologies to operate in both urban and rural areas on highways that are instrumented or not instrumented.

The long term goal of the AHS program is to successfully deploy an automated highway system. However, initial assessments are needed to determine the impact of various system configurations on conventional construction and maintenance operations.

Enclosed is a video tape entitled, "IVHS Technologies for Transportation" from the U.S. Department of Transportation that will provide additional information on the conceptual architecture and operation of an AHS. This questionnaire was developed based on this model of an AHS.

For additional information or clarification regarding this questionnaire please contact:

Mimi Huie
Public - (916) 654-8014
Calnet - 8-464-8014

or

Tom West
Public - (916) 654-8016
Calnet - 8-464-8016

Facsimile - (916) 657-4580
email: tmlmimih@tr2.dot.ca.gov

Facsimile - (916) 657-4580
email: tmltomw@tr2.dot.ca.gov

Please return this questionnaire to:

State of California, Department of Transportation
Division of New Technology, Materials and Research
Office of Advanced Vehicle and Infrastructure Development
Maintenance and Construction Technology Branch
P. O. Box 942873, MS-83
Sacramento, CA 94273

DIVISION OF MAINTENANCE

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

Scenario 1:

- **only light weight, automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Scenario 2:

- **all (light weight and heavy weight), automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
 - Note:* - The magnetic nails are 25.4 mm in diameter and 10.2 cm in length, flush with the pavement surface and placed at 91.4 cm intervals.
 - Passive/Active wires can be slot cut into the middle of the pavement similar to the installation of detector loops.
- The implementation of vehicle guidance and control can potentially increase highway capacity. For example, vehicle longitudinal control can reduce operating headways (distance between vehicles), and vehicle lateral control has the potential to reduce conventional lane widths.
- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS FOR BOTH SCENARIOS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. How would the maintenance of pavement compare with conventional procedures?

3. **Vehicle lateral control has the potential to increase the capacity of the conventional highway system configuration by reducing the lane width. How would highway lanes with reduced widths be maintained? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?**

4. Assume larger volumes of traffic traveling at higher speeds. Do you envision that maintenance operations need to be automated to meet the needs and demands of the traveling public in a fully automated highway system? Explain.
5. What type of tasks can be automated to facilitate the maintenance of this system configuration?

6. What are some potential changes that will directly affect maintenance operations?

7. What special lane closure procedures will be required?

10. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

APPENDIX B

Sample Survey Questions

STRUCTURES

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

- Only light weight vehicles operate on elevated structures that may be located above the median, outer separation or conventional highway lanes. The elevated structure consists of two opposing highway lanes that are physically separated by a barrier with breakdown lanes available for vehicle failure and emergency response.

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
 - Note:* - The magnetic nails are 25.4 mm in diameter and 10.2 cm in length, flush with the pavement surface and placed at 91.4 cm intervals.
 - Passive/Active wires can be slot cut into the middle of the pavement similar to the installation of detector loops.
- The implementation of vehicle guidance and control can potentially increase highway capacity. For example, vehicle longitudinal control can reduce operating headways (distance between vehicles), and vehicle lateral control has the potential to reduce conventional lane widths.
- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

- 1. How would the design, construction and maintenance of elevated structures differ from conventional means assuming light weight vehicle use only?**
- 2. What are the considerations in the design, construction and maintenance of an elevated structure that is instrumented with reference sources and power and communication distribution systems?**
- 3. Would it be feasible to construct an elevated structure using lightweight, prefabricated sections? Could prefabricated columns be used where applicable? Is it feasible for automated machinery to be used for the assembly of such sections if the sections are designed for ease of assembly? Explain.**
- 4. What other type of tasks might be automated to facilitate construction and maintenance of this system configuration?**
- 5. Do you perceive any problems with retrofitting the conventional structures with reference sources?**

6. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

Scenario 1:

- **only light weight, automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Scenario 2:

- **all (light weight and heavy weight), automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
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- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS FOR BOTH SCENARIOS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. How would the design of a highway (in regard to pavement, sub-base and geometrics) be different from current designs?
2. Could the lane delineation in a designated, automated highway lane be delineated differently to accommodate a reference system? (For example, could a lane stripe be painted down the center of a highway lane for vehicle lateral control using a vision system or could raised pavement markers be placed down the center of a highway lane for vehicle lateral control using a laser system?) Explain.
3. What design considerations can facilitate the automated construction and maintenance operations of this system configuration?

4. If conventional highway lane widths are reduced to 2.4 m to 2.7 m what is the effect on pavement (i.e. width, cross slopes), shoulder and median specifications? What would change if the vehicle width is reduced to 1.2 m to accommodate small commuter and neighborhood vehicles?
5. How would conventional cross section specifications change? Explain.
6. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

DIVISION OF CONSTRUCTION

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

Scenario 1:

- **only light weight, automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Scenario 2:

- **all (light weight and heavy weight), automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
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- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS FOR BOTH SCENARIOS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. How would the construction of a highway lane (i.e. sub-base and pavement, etc.) compare with current procedures?
2. Could automated construction equipment be used for the installation of the reference sources (i.e. magnetic nails, passive wire, active wire, etc.) that are embedded in the pavement? Explain.
3. Could light weight sections of the highway be prefabricated off-site and installed at the construction site? Explain.
4. What potential exists to use automated machinery for construction? Could you envision using robotics to assemble pre-fabricated sections?

5. What types or barrier systems could be used to segregate highway lanes? How would these barrier systems be installed?
6. Could staged construction be used to modify the conventional highway? For example, could the physical barrier be constructed before the new highway lane is constructed? Explain.
7. Vehicle lateral control has the potential to increase the capacity of the conventional highway system configuration by reducing the lane width. How would highway lanes with reduced widths be constructed? Would special construction vehicles be needed? What requirements would such vehicles need to satisfy?
8. What are some potential changes that will directly affect construction operations?
9. Do you perceive any problems with retrofitting the conventional structures with reference sources?
10. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

DIVISION OF MAINTENANCE

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

Scenario 1:

- **only light weight, automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Scenario 2:

- **all (light weight and heavy weight), automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
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- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS FOR BOTH SCENARIOS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. How would the maintenance of pavement compare with conventional procedures?
2. Would a specialized maintenance procedure be needed to inspect the reference sources embedded in the pavement? Explain.
3. Vehicle lateral control has the potential to increase the capacity of the conventional highway system configuration by reducing the lane width. How would highway lanes with reduced widths be maintained? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?
4. Assume larger volumes of traffic traveling at higher speeds. Do you envision that maintenance operations need to be automated to meet the needs and demands of the traveling public in a fully automated highway system? Explain.

5. What type of tasks can be automated to facilitate the maintenance of this system configuration?
6. What are some potential changes that will directly affect maintenance operations?
7. What special lane closure procedures will be required?
8. Could maintenance operations take advantage of the new AHS configuration for increased safety and efficiency of maintenance tasks (i.e. use of AHS vehicle guidance and control system)? Explain.
9. What additional maintenance operations will be required to maintain an elevated structure that is dedicated for light weight vehicles only? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?
10. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

TRAFFIC OPERATIONS

System Configuration

The system configuration for an AHS that is under consideration is different from the conventional transportation system such that:

- **all (light weight and heavy weight), automated vehicles** operate on new highway lanes that may be located in the median or outer separation and adjacent to conventional highway lanes.
- designated automated highway lanes are segregated by barriers that physically separate non-automated vehicles from automated vehicles.

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
 - Note:* - The magnetic nails are 25.4 mm in diameter and 10.2 cm in length, flush with the pavement surface and placed at 91.4 cm intervals.
 - Passive/Active wires can be slot cut into the middle of the pavement similar to the installation of detector loops.
- The implementation of vehicle guidance and control can potentially increase highway capacity. For example, vehicle longitudinal control can reduce operating headways (distance between vehicles), and vehicle lateral control has the potential to reduce conventional lane widths.
- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS FOR BOTH SCENARIOS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. How would current traffic operations be affected in a fully automated highway system? (i.e. congestion relief, increased incident response time, reduced number of incidents, etc.)
2. What special procedures will be required to facilitate emergency response situations (i.e. accidents, fire, hazardous spills, etc.)?
3. Could traffic operation take advantage of an AHS system configuration to facilitate emergency response situations?
4. Could a traffic operation center assist in maintenance and construction operations (i.e. divert automated vehicles traveling on an automated highway lane to another automated highway lane)? Explain.
5. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

PAVEMENT

Assumptions

- Some level of roadway intelligence (passive or active) needs to be embedded into the pavement. Magnetic nails, passive wire or active wire are example reference sources that may be used for vehicle guidance and control.
 - Note:* - The magnetic nails are 25.4 mm in diameter and 10.2 cm in length, flush with the pavement surface and placed at 91.4 cm intervals.
 - Passive/Active wires can be slot cut into the middle of the pavement similar to the installation of detector loops.
- The implementation of vehicle guidance and control can potentially increase highway capacity. For example, vehicle longitudinal control can reduce operating headways (distance between vehicles), and vehicle lateral control has the potential to reduce conventional lane widths.
- Vehicle operational speed may approach 128.7 km/h.

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. Would the installation of reference sources embedded in the pavement affect the durability and integrity of the pavement on conventional highway lanes? Explain.
2. Assume that the system configuration is designed such that a designated, automated highway lane supports automated vehicles that laterally travel in the same path on the pavement. What effect might automated vehicles have on the pavement in regards to pavement degradation due to constant wheel contact at the same location (channelization)?
3. What specialized materials/construction procedures are available to reduce the effects of channelization in the pavement?
4. What effect will the elimination of heavy vehicles have on pavement design and maintenance?
5. How would pavement cross sections be designed differently based on embedded reference sources?
6. Would an AHS assist in pavement integrity assessment management (i.e. vehicles used as information probes)? Explain.
7. Can you identify an existing highway section as a site for a demonstration of an AHS?

COMMENTS:

NEW TECHNOLOGY

Questions

PLEASE ANSWER QUESTIONS BY ADDRESSING SAFETY, COST AND TECHNICAL ASPECTS WHERE APPLICABLE. (USE ADDITIONAL SHEETS AS NECESSARY.)

1. Envision an AHS system. What does it look like? How does it operate? Please provide a detailed description.
2. Could you visualize automating the construction and maintenance operations to support an AHS? Explain.
3. Could you visualize how maintenance operations might benefit from an AHS? Explain.

COMMENTS:

APPENDIX C

Sample Survey Responses

MAINTENANCE

1. How would the maintenance of pavement compare with conventional procedures?

- A. Care would have to be taken so as not to damage or interfere with devices implanted into pavement thereby increasing time of work.
- B. The maintenance of pavement with magnetic nails would require changes in maintenance procedures because the nails are flush with the surface and would require raising if any overlay or cover was added. Where passive/active loops are used, pavement maintenance could be the same as is used now. It being acceptable to pave or seal over the loops.
- C. There would be significant increases in the cost of pavement maintenance due to the need to maintain the operation of either the nails or wires. Existing loop detectors have a high failure rate (especially on PCC Pavement) due to movement and flexing of the pavement.
- D. Getting involved with weather stations and pavement sensors has shown that when overlays are done, the sensors are replaced. They wear out. It will be costly to do this. Caltrans will have to hire more electrical specialists to maintain all of these electrical components. If we could segregate trucks onto separate lanes and keep them there, the pavement wouldn't wear out as fast and we wouldn't have to change sensors as fast.
- E. "Assumptions", above, does not state whether pavement would be rigid or flexible. Need to embed guidance and control favors a rigid "maintenance free" structural section, probably fully-reinforced concrete. This would be much more difficult to obtain under heavy loads (Scenario 2).
- F. Special precautions will be needed during pavement maintenance such as grinding, patching, and sealing so as not to damage or affect the accuracy of the pavement components.

Conduit or raceway could be embedded in the roadway and all of the guidance equipment could be placed in it. This would solve the problem of damage to conductors caused by pavement cracking.

- G. Vehicles can be automatically directed around the work zone.
- H. If the vehicle guidance and control devices are placed at the surface of the pavement then they could be affected by typical maintenance activities such as spall and crack repair, pothole filling and slab replacement. PCC rehabilitation and grinding could require complete replacement of these devices. AC is a flexible pavement and may not even be suitable for hosting these devices. These devices may be negatively affected by typical operations like chip seals, fog seals, and thin blanket overlays. Alternatives to consider would be a raceway between two paved wheel tracks or

mounted on the barrier system. Both would improve access for repair and eliminate the problems associated with embedding.

- I. We could no longer just overlay the pavement. A great deal of extra effort and cost would be required to preserve the roadway intelligence. Operating speeds of 128.7 km/h would require extended lengths of traffic control and warning devices. Windows of time for pavement maintenance would become smaller as capacity was used up. Shorter headways and narrow lanes will increase the density of traffic.
- J. No major change in current problems. The facility would have to be closed to perform maintenance on the pavement for safety.

2. Would a specialized maintenance procedure be needed to inspect the reference sources embedded in the pavement? Explain.

- A. Not necessarily. Monitors could be installed on maintenance vehicles allowing them to travel at prevailing speeds and automatically recording source performance.
- B. Some type of specialized equipment/machine would be required to test the operation of the reference sources embedded in the pavement. Malfunctions could be the cause of accidents.
- C. Yes. If there is a need to check electrical circuit operation, then special procedures and equipment will need to be developed.
- D. I believe we would have more reactionary than planned maintenance program. We don't have the personnel to go out and inspect all of the reference sources embedded in the pavement.
- E. Continuous wire on cable could be inspected remotely by continuity checks. Magnetic nails would probably require a vehicle mounted inspection system.
- F. More than likely, a diagnostic system test equipment will be needed to determine the functionality and accuracy of the system components.

This additional equipment will require special procedures to inspect and repair and resources to train personnel.

- G. A maintenance classification and scope sheet must be developed and staffed, i.e., "Caltrans computerized system technician";
Scope: inspection, calibration verification, maintenance, repair, troubleshoot, reprogram. Actual operation will be the responsibility of others.
- H. Probably will need special equipment and procedures to inspect these new devices. In addition we will need to train the people to use this new equipment which could require considerable effort. A real unknown is how often these devices will need attention? If it becomes a very common need to go out and service them this will increase our worker exposure time around traffic.
- I. If the intelligence devices were redundant, that is more were placed than absolutely necessary, then we could stand some failures of individual devices.
We should set up local hubs that an inspector could monitor and pinpoint individual device failure rather than test each device in the roadway.
- J. Inspection or test procedures developed so the inspection could be performed while the facility (is) open.

3. **Vehicle lateral control has the potential to increase the capacity of the conventional highway system configuration by reducing the lane width. How would highway lanes with reduced widths be maintained? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?**
- A. Special vehicles would be required depending upon the degree of width reduction.
 - B. Special maintenance equipment should not be required because lanes are narrower. It would be necessary to close adjacent lanes to give the required buffer zone between moving traffic and workers. This is required now with present lane widths for safety reasons.
 - C. Yes. Existing maintenance vehicles require a minimum lane width of 3.4 m in order to operate. Special vehicle would have to be developed especially if clearance between protective barriers is less than 3.4 m. These special vehicles could only be used in these special lanes and they may not be cost effective unless they are used on a daily basis.
 - D. It may change the way we strip(e) or put pavement markers down.
 - E. Special vehicles would probably be needed especially if snow and ice removal is to be considered.
 - F. Reduced lane width may affect the safe area that maintenance personnel need to work in special situations where access to the travel lane is required for certain maintenance repair.

These vehicles could be designed with robotics in mind. That is they could be much smaller and would not need space for an operator thus the need for safety requirements would be lessened.

- G.
 - a. Maintain lanes by automatic offset which will direct vehicles around a maintenance operation.
 - b. Maintenance vehicles need the same controls as other lane users. They also need additional electronics to coordinate maintenance operations with the TMC.
 - c. They must be reliable.
- H. If lane widths are reduced and barriers are used on both sides, then the majority of the maintenance fleet will have to be designed for the system. Incorporation of the guidance into the maintenance vehicles should enhance maintenance activities by allowing automation or leave operators to attend to activities other than guiding the vehicle. The types of activities which will need consideration are:
 - Sweeping (1)
 - Cracking Sealing (2)
 - Patching (2)
 - Resurfacing (2)
 - Grinding (1)
 - Electric and Electronics Repair (2)
 - Snow Removal (3)
 - Litter Gathering (1)

Notes:

- (1) Could be fully automated and possibly unmanned. The activity could be incorporated into platoon schedules.
 - (2) Would require lane closure.
 - (3) Storage of removed snow would be a very difficult problem. The barriers would present normal plowing because there is no place for snow to be stored and snow blowers can only operate at 4.8 km/h to 8.0 km/h.
-
- I. If the control devices were longitudinal and were located at the limits of each lane, then smaller equipment might be required to avoid contacting the control devices. Smaller maintenance vehicles could not provide shadow protection for maintenance crews.
 - J. Depends on the width of the facility if special equipment (is) needed. Minimum 3.0 m needed for today's vehicles.

4. Assume larger volumes of traffic traveling at higher speeds. Do you envision that maintenance operations need to be automated to meet the needs and demands of the traveling public in a fully automated highway system? Explain.

- A. Yes - If there are separate lanes for automated and conventional traffic.
- B. Larger volumes of traffic and higher speeds demand the change to and use of automated or mechanized maintenance operations. However, everything cannot be done by a machine and some problems must be worked by hand.
- C. The lanes would have to be shut down for a minimum of four hours each night in order to perform routine maintenance. Automated maintenance vehicles have not been successful in Caltrans.
- D. Yes - If only for efficiency needs.
- E. Yes - For instance, liquid deicing chemicals could be automatically sprayed on the road surface when remote sensors indicate such treatment is warranted.
- F. Scheduled maintenance operations may be scheduled and planned rather than automated to meet the demands of an AHS. However, unplanned failures and problems could still constitute a large percentage of the maintenance man-hours to maintain such a system.

This may lead to increased night work if the volumes during the day are high.

- G. Long tapers can be eliminated. Automatic self-contained barrier vehicles are needed instead of traffic cones and signs.
- H. Yes. There would be a need to automate maintenance operations for improved worker safety. With more volumes and higher speeds, there will also be more restrictions on times that maintenance can be performed. This may lead to more night work for maintenance workers which has increased safety concerns.
- I. Yes. I would not want maintenance personnel exposed to the higher volumes at increased speeds. An automated maintenance program could be used at any time rather than trying to schedule a night shift.
- J. Not necessarily. Maintenance cannot occur at high speeds. The facility will have to be closed periodically for maintenance activities.

5. What type of tasks can be automated to facilitate the maintenance of this system configuration?

- A. Sweeping, striping and lane detector malfunctions.
- B. The testing/cleaning of the system could be automated. Monitoring the system could be done by sensors and video monitors to ensure proper operation or immediate awareness of a problem.
- C. Electronic circuits could be checked with automated devices. Roadbed maintenance could not be automated.
- D. System checks. The system needs to have automated checking system to facilitate repairs. It would be costly if we had to do this manually.
- E. See above.
- F. We cannot envision any automated maintenance operation other than self-diagnostics which is a problem sensor rather than a corrective procedure.

A vehicle could be operated remotely without an operator if it were to follow the automated system. It could then record problem areas by post mile or post kilometer for further repairs.

- G. *No response.*
- H. Need to know more about the proposed system to answer fully what can be automated.

Should try to automate facility opening and closing. Special diagnostic equipment should be able to evaluate, while in motion, whether the system needs adjustment and be able to make those adjustments without exposing workers to traffic.

- I. Crack filling, overlays, sweeping, sealing and longitudinal slot cleaning.
- J. Debris removal and replacement and repair of the guidance system.

6. What are some potential changes that will directly affect maintenance operations?

- A. Employees will have to be more technically qualified.
- B. The installation of nails/loops in all the lanes will change the way repairs can be made.
- C. Employees would to learn electronics skills. There would be a need for new testing procedures, new materials and training.
- D. If we can utilize the technology to control tracking of maintenance equipment, then we can do maintenance more efficiently. For example, control the tracking of striping machine and do striping at higher speeds.
- E. I don't understand the question.
- F. This kind of system will demand more maintenance personnel, extensive training, and specialized instruments to effectively keep this system in operation at a desired level.
- G. Nails must work when overlayed. Saw cuts chip out under traffic. PCC slabs move and will cut the embedded wire.
- H. Will need a skilled workforce to maintain this high tech facility. This will come from increased training and/or the hiring of higher skilled workforce.

Certain maintenance operations that require a special skill and special equipment may be cost-effective to Contract out. One such item may be the field repair of fiber optic cable.

- I. Automation will reduce person needs, at least on the road.
- J. The width of the facility. The level of maintenance required.

7. What special lane closure procedures will be required?

- A. This question would be answered following knowledge of lane configuration. Most probably would require advance information technology in vehicles.
- B. Lane closure procedures might be changed by having movable gates/K-rail at certain intervals. If more than one lane has sensors then it might be possible to use a portable temporary strip of sensors to divert vehicles to adjacent lanes. Protection of workers should still be prime concern.
- C. See response to question #4. System would have to be closed down in order to routine maintenance similar to what occurs on rail transit systems.
- D. I don't know.
- E. Automated vehicles will probably have to be slowed and merged with non automated traffic at pre-determined locations and specific sections closed for repair.
- F. We anticipate more frequent and longer lane closures are required to repair pavement-embedded components.

Perhaps automated lane closures could be employed. Similar to that used at the Caldecott tunnel.
- G. No lane closures are needed, only a short positive barrier.
- H. Automated lane closures will be desirable. See also answer 5.
- I. Automation of the highway and its users will make lane closures easier due to all traffic being controlled. Automation will reduce the need for physical protection, but probably increase the need for advance warning.
- J. Use of "Safety Net" possibly.

8. **Could maintenance operations take advantage of the new AHS configuration for increased safety and efficiency of maintenance tasks (i.e. use of AHS vehicle guidance and control system)? Explain.**

- A. Possibly. Stripers and sweepers come to mind.
- B. Yes, as described in response to question 7. Gates/K-rail could be used to close off the separate AHS lanes. Or temporary sensors could be used to direct vehicles away from workers or cause vehicles to stop if entering area of workers.
- C. No.
- D. Yes, see previous statement.
- E. Only if:
 - 1) Those tasks can be done at the speed of surrounding traffic.
 - 2) Traffic can be slowed to the speed of the task.
 - 3) Other vehicles are removed.

If other vehicles are removed guidance and control might be used for surface restoration and repair operation..
- F. If this system can keep all vehicles in a controlled lane area and eliminate errant vehicles, it can improve the safety of maintenance personnel working on shoulders or lanes that are programmed out of operation.
- G. *No response.*
- H. Yes. If system is barrier separated from traffic. If we can develop multi-functional equipment that can be operated by fewer workers. Equipment could be unmanned and controlled from TMC or elsewhere. Less exposure to workers. For example, sweepers could be part of the platoon or spared between platoons and be unmanned.
- I. Same response as #7.
- J. May be able to use driverless vehicle on the facility.

9. **What additional maintenance operations will be required to maintain an elevated structure that is dedicated for light weight vehicles only? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?**
- A. Lighter maintenance equipment. Access below structures for ease of inspections.
 - B. Caltrans already maintains elevated structures. It would require expanding these functions and acquiring the additional vehicles/equipment used in the maintenance of elevated structures.
 - C. Would need snoopers trucks to inspect structures. Would need access under structure for inspection, maintenance and repair. Structure maintenance requires a different crew as well as equipment and training compared to roadway maintenance.
 - D. Graffiti removal, joint seals if necessary.
 - E. Unknown.
 - F. No opinion at this time.
 - G. Not enough information to comment.
 - H. An elevated system would require maintenance similar to current structure related maintenance. Special vehicles may be needed to access this facility. Columns from this elevated structure that was placed along the median or shoulders could encroach into the recovery area currently used for normal vehicles. This space is also used for staging of maintenance activities and could inhibit their current procedures; i.e., no shoulder closures. Any specialized roadway equipment could be accessed from within the structure instead of from the roadway surface.
 - I. Additional structural inspectors, additional interchanges with conventional traffic and maintenance vehicles would need to be light and yet still able to carry tools and equipment needed for work.
 - J. *No response.*

10. Can you identify an existing highway section as a site for a demonstration of an AHS?

- A. None in District 1.
- B. I believe State Route 118 between City of Moorpark and Interstate 5 or State Route 23 between City of Moorpark and City of Thousand Oaks could be used. Both highways have wide medians and are scheduled for future additional lanes.
- C. San Francisco - Bay Bridge in District 4.
Sacramento - Freeway section in North Sacramento.
- D. No, but maybe we can use the old RR R/W and build structures at intersections. I-5 would be another possibility.
- E. Route 14 between Rosamond and Lancaster is straight, flat and has room in the median for additional facilities. It is close to the Los Angeles area, but not yet so choked with traffic as to make experimentation hazardous.
- F. Route 280 in San Mateo county south of Highway 92.
- G. No.
- H. In District 3 along the Yolo Causeway. This is a 5.3 km stretch that is straight and has no entrance and exit ramps and includes a bike path with barrier.

In District 4 on the San Mateo or Dumbarton Bridge. This is a 10.9 km mile stretch.

In District 11 on the Coronado Bay Bridge and along I-15 in the reversible HOV lanes.
- I. Not in District 6.
- J. No.

Comments

- A. *No response.*
- B. *No response.*
- C. Make sure that maintenance resources are provided at start up. Make sure that system is debugged before you experiment on the public.
- D. *No response.*
- E. *No response.*
- F. *No response.*
- G. *No response.*
- H. *No response.*
- I. *No response.*
- J. Better information could be obtained by meeting with various groups to discuss the needs of the AHS. Information in this questionnaire is too vague.

CONSTRUCTION

1. **How would the maintenance of pavement compare with conventional procedures?**
 - A. Very little difference except for the embedment of sensors assuming the wheel loads and other design criteria remain unchanged.
2. **Would a specialized maintenance procedure be needed to inspect the reference sources embedded in the pavement? Explain.**
 - A. Yes, industry will develop equipment if the demand is there.
3. **Vehicle lateral control has the potential to increase the capacity of the conventional highway system configuration by reducing the lane width. How would highway lanes with reduced widths be maintained? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?**
 - A. Probably, as almost anything can be done. It all demands upon the economics. A major concern would be in obtaining satisfactory ride quality.
4. **Assume larger volumes of traffic traveling at higher speeds. Do you envision that maintenance operations need to be automated to meet the needs and demands of the traveling public in a fully automated highway system? Explain.**
 - A. Answers to #2 and #3 apply here also.
5. **What type of tasks can be automated to facilitate the maintenance of this system configuration?**
 - A.
 - Concrete barrier slip-formed.
 - Concrete barrier precast.
 - Metal barrier constructed in place.
 - A positive barrier should be installed to prevent wayward vehicles from entering the lane.
 - A positive barrier should be installed to reduce maintenance exposure to traffic when making repairs (i.e., light weight or temporary type barriers usually require immediate maintenance when hit).
6. **What are some potential changes that will directly affect maintenance operations?**
 - A. Yes. It is done today where reversible HOV lanes are constructed. On widening projects, temporary concrete barrier (K-rail) is placed prior to construction of the widening.

7. What special lane closure procedures will be required?

- A. Many pieces of equipment now are adjustable down to 2.4 m widths. We doubt widths will be reduced to less than 2.4 m. As noted previously in No's 2 and 3, if demands are high enough and the economics are there, industry will adapt.

8. Could maintenance operations take advantage of the new AHS configuration for increased safety and efficiency of maintenance tasks (i.e. use of AHS vehicle guidance and control system)? Explain.

- A.
- Reducing lane widths.
 - Adapting to placement of new technology products.
 - Understanding specifications for new products and installation tolerances.

9. What additional maintenance operations will be required to maintain an elevated structure that is dedicated for light weight vehicles only? Would special maintenance vehicles be needed? What requirements would such vehicles need to satisfy?

- A. Yes, there will be a conflict between existing deck reinforcing steel and embedded sensors. Reinforcing steel usually has a 38.1 mm to 50.8 mm cover of concrete. The proposed embedment is somewhere in the 10.2 cm deep range.

10. Can you identify an existing highway section as a site for a demonstration of an AHS?

- A. Ideally, an urban route. Most of these in the San Francisco Bay area would require the lanes be elevated or funneled because of the lack of R/W. Possibly, there are sections along Routes 280 and 880. In District 07, some of the less congested routes may provide a possibility. In District 03, perhaps the Route 99 widening between Mack Road and Elk Grove Blvd. would be a possibility.

Comments

- We see no significant difference between scenarios 1 and 3 for construction.
- Can the sensors pickup partial lane encroachment of debris from an accident in adjacent lanes?

PAVEMENT

1. Would the installation of reference sources embedded in the pavement affect the durability and integrity of the pavement on conventional highway lane?

- A. The "installation" of nails may cause spalls in AC and probably would cause spalls in PCC. This would create some debris that would have to be removed and would result in the protrusion of the top of the nails, thereby creating the likelihood of their being dislodged or bent by traffic. The recesses caused by the spalls would collect surface water that may have some effect on the nails (corrosion). This would also provide a possible path for some surface water to enter or move through the pavement but I doubt that this would have a significant effect on pavement performance.

I do not foresee any detrimental effect on pavement due to the installation of wires in slots cut into the pavement assuming that the slots are relatively shallow (say 12.7 mm to 19.1 mm deep).

2. Assume that the system configuration is designed such that a designated, automated highway lane supports automated vehicles that laterally travel in the same path on the pavement. What effect might automated vehicles have on the pavement in regards to pavement degradation due to constant wheel contact at the same location (channelization)?.

- A. The only effect on PCC pavement that I would anticipate would be an acceleration of the rate of rutt development where tire chains are used. On AC pavements, I would anticipate a significantly acceleration in rutt development. An initial effort to study this was completed last year. The draft final research reports were sent to the FHWA for review on March 2, 1994. The results of this testing revealed an increase in rutt depth of approximately 30% and 50% (for the two temperatures studied) when wandering traffic was channelized. Because rutting is difficult form of pavement distress to alleviate and because this type of distress requires fast action due to safety concerns associated with the pounding of water in ruts, the effect of channelization on rutting deserves considerable study.

3. What specialized materials/construction procedures are available to reduce the effects of channelization in the pavement.

- A. Wearing surfaces such as polyester concrete have been utilized with some success on bridge decks and on I-80 PCC pavement in the snow county. However, this material is expensive, even when placed in relatively thin layers (19.1 mm \pm). Also, I am not sure about its compatibility with the installation of nails or wires to obtain the lateral guidance. Regarding AC, there are some modified mixes that might provide the increased rutt resistance that would appear to be needed because of traffic channelization. Both stone mastic asphalt (SMA) and rubber-modified AC are possibilities.

4. **What effect will the elimination of heavy vehicles have on pavement design and maintenance?**
 - A. Caltrans (and others) have done some research on this subject. The elimination of heavy vehicles would result in a significant service life extension for existing pavements. It would also significantly reduce the cost of future new construction if designed for only light vehicles.
5. **How would pavement cross sections be designed differently based on embedded reference sources?**
 - A. Because of the problems associated with driving nails into complete pavements (see number 1 above), the use of embedded wires would be preferable. In either case, I foresee no design (thickness) adjustments due to the embedded sources. I don't know whether typical pavement smoothness is compatible with these systems - (i.e., would the pavement smoothness specs have to be tightened up?) I foresee no significant problems when modifying pavers to embed reference sources in AC or PCC during or immediately after placement of the pavement.
6. **Would an AHS assist in pavement integrity assessment management (i.e. vehicles used as information probes)? Explain.**
 - A. No.
7. **Can you identify an existing highway section as a site for a demonstration of an AHS?**
 - A. Perhaps at least slow-speed demonstrations could be accomplished at an abandoned military base (Mather Air Force Base or Norton Air Force Base). Other possibilities might be the current (or the old) CHP Academy, I-80 near the Watt Avenue light rail station where some abandoned pavement exists, or locations identified by design or construction where existing alignments that are scheduled for abandonment, demolition, or relinquishment to a local agency.

Comments

- A. *No response.*

DESIGN

1. How would the design of a highway (in regard to pavement, sub-base and geometric) be different from current designs?

A.

1. Would curve radii have to be adjusted for the 128.7 km/h?
2. Access and screening for vehicles in emergencies may be a problem; disabled vehicles between barriers will need to be removed somehow.
3. PCC structural section would possibly cause cracking along the center line if nails were used. AC pavement might also be affected.

Scenario 1 - could use a smaller depth structural section or even existing shoulder sections because of lighter weight requirements.

B. In Scenario 1: pavement structural section could be reduced.

Since geometrics are based on several factors (design, speed, drainage, etc.), some geometrics might change, i.e., minimum curve radius, while others may not change, i.e., stopping sight distance requirements.

C.

- Thinner section.
- Narrower section.
- Lane delineation not required.
- Shorter roadways because they are faster.
- Need more cars to fill spaces.

D.

1. 50% reduction in structural section in Scenario 1.
2. System failure--What type of backup--mitigate effects of immediate.
Obtaining R/W.
Human nature.
3. Higher speeds -- system failure.
4. Compatibility of new high geometrics with conventional highway.
5. Interfaces with convention system. May be difficult.

E. See #3.

F. S-1: Less depth of section, reduced cost.
S-2: Must be able to handle heavy weight.

G. Highway design would not change; weight of vehicles, drainage cross slopes & lane delineation must be maintained because the highway will still be used for the same purpose -- moving goods and people. Because I would design a system for use on the existing roadway working along with manual vehicles, any system that is totally separate would be prohibitively expensive. (See Attachment).

2. **Could lane delineation in a designated, automated highway lane be delineated differently to accommodate a reference system? (For example, could a lane stripe be painted down the center of a highway lane for vehicle lateral control using a vision system or could raised pavement markers be placed down the center of a highway lane for vehicle lateral control using a laser system?) Explain.**
- A. This can be done:
- With night time driving would vision system work.-- snow covering lane? oil covering lane?
 - With raised pavement markers the system will have to distinguish between debris and the pavement markers -- also what about ice and snow?
- B. Yes, delineation is merely a way to show the drivers where to drive. The configuration could change but only with adequate education of the drivers.
- C. YES! & NO! Stripe not required. Vehicle position is controlled.
- D. Keep it simple. No changes in delineation except to designate that lane has IVS capabilities.
- E. A passive lane stripe, possibly magnetic or reflective in nature, could be used very easily with the detection system on board the vehicle. An active stripe would have to be continuous, and any break in the stripe would cause current to stop flowing through the stripe. The idea won't work because vehicles directly ahead will block any beams the on-board sensor sends out. The on-board sensor would be restricted to making lane correction on stripes only 6.1 m to 9.1 m ahead of the vehicle, which would not give the vehicle time adjust speed for upcoming changes in road alignment. If you can get this to work, it has tremendous benefits for driving at night or in the fog. Snow will cover any visual system, and snow removal equipment will ruin any above surface devices.
- F. S-1, S-2: Would this lateral control allow vehicles that are broken down or need to move off onto the shoulder? If so, a reference line is needed to delineate a "safe zone." Consideration is needed during the transition period. At the end of the highway system connecting to a city system, a center stripe is needed on the city system. Currently, a single lane city system has no center stripe.
- Not changing striping patterns would allow the new system to tie into existing system easier.
- G. See Attachment .

3. **What design considerations can facilitate the automated construction and maintenance operations of this system configuration?**
- A. Make an optional direction lane for commute traffic with a controlled, movable barrier which changes with the direction of commuter traffic.
Integrate non automated and automated vehicles in the system.
 - B. Local streets would need to be upgraded to handle overflow from freeway resulting from rerouting traffic.
Even with segregated traffic, shoulders would still be necessary for emergency use and maintenance vehicles.
 - C.
 - Safety refuge on both sides of roadway.
 - Require operation check of equipment.
 - NRA opposed.
 - D.
 - 1. Reaction time after power failure.
 - 2. Mechanical failures on individual vehicles.
 - 3. Ingress security for automated highway lanes.
 - 4. (Urban highways, local streets, rural highways). Phasing of implementation.
 - E. Paving machines would have to be able to place the detectors such as magnetic nails or wires. Also, these detectors must be accessible through the pavement for maintenance. Longitudinal detectors could separate due to transverse pavement cracking, so a very flexible detection system will be a must (earthquake deflections will probably govern how far they can separate).
 - F. Since automated highway will be added to current system and automation cannot happen at one time, both automated and non-automated vehicle will share on & off ramps? If not, then each need their own. I suggest, possibly, in dense areas, allow every other on & off to be automated. Then only the city system will have both auto- and non-automated on the same system.
 - G. See Attachment.

4. **If conventional highway lane widths are reduced to 2.4 m to 2.7 m what is the effect on pavement (i.e. width, cross. slopes), shoulder and median specifications? What would change if the vehicle width is reduced to 1.2 m to accommodate small commuter and neighborhood vehicles?**
- A. Depends upon vehicles weight. If weight is reduced, structural depth can be reduced, and smaller cars require smaller lane widths.
Mixed vehicle sizes (ex 1.2 m) may be a problem. Would local streets accommodate 4 foot wide vehicles?
- B. Cross slopes shouldn't change since they are needed for pavement drainage. Of course, shoulder width could be reduced if vehicle widths are reduced (unless emergency and maintenance vehicles are standard size).
- C.
- Obviously the space requirements and buffers are reduced.
 - Cross slope is for drainage.
 - Shoulders & median not needed.
- D. May need wider median.
- E. 2.4 m to 2.7 m lane widths put the longitudinal pavement joint on most highways in the wheel path, which will cause quicker pavement failures.
- All vehicles cannot be 1.2 m wide, so they will have to mix with trucks. Also, motorcycles get hit often because their small size makes them hard to see, so the same problem could occur with 1.2 m wide vehicles.
- F.
- If vehicle can travel 128.7 km/h, current super elevations may not be acceptable.
 - The more reduced lanes will allow a greater number of lanes in a given width; however, this may significantly increase weaving distance to an exit.
- G. See Attachment.

5. How would conventional cross section specifications change? Explain?

- A. It depends upon how wide the new lane would be.
128.7 km/h - super elevated section may have to change
- B. Reducing lane widths might reduce R/W width requirements.
- C.
 - Must be in metric dimensions.
 - Narrower corridors.
 - No CRZ.
 - No safety setbacks.
- D. Should not change because still have to accommodate conventional traffic.
- E. *No response.*
- F. See above.
- G. See Attachment.

6. Can you identify existing highway section as a site for a demonstration of AHS?

- A. Yolo causeway bikeway!
I-5 in Districts 10 or 6.
Could system be somehow tied into the Weight Station Bypass Systems (AVI)
Automated Vehicle Identification to be installed at the Los Baños Weigh Station?
- B. Sacramento Co.: Business 80 from split to West Sac. That way we can watch the fun
from our office.
- C. Bonneville Salt Flats.
24/580/980 Interchange.
- D. SB I10.
I80 North of Sacramento.
Rt. 41 in Fresno: Fog, commuter traffic.
- E. *No response.*
- F. Route 80 from S.F. to Sac.
- G. In San Diego, the reversible HOV lanes.

Comments

- A. *No response.*
- B. *No response.*
- C. Safety and Security will be critical.
Someone else is assuming control of my vehicle.
"Big Brother Control".
- D. *No response.*
- E. Scenario #2 is dangerous because future lightweight vehicles will probably be electric, and it will be very dangerous to mix lightweight electric cars and diesel trucks.

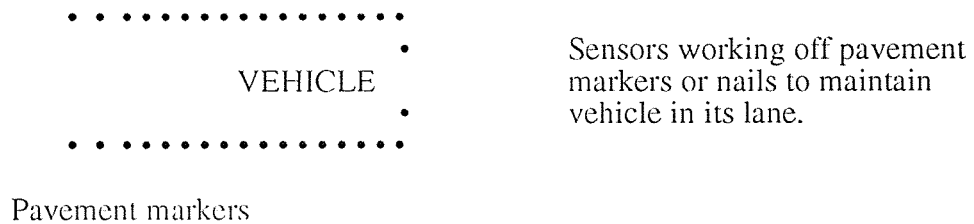
Snow will cover any visual detection system and make infrared difficult.
- F. *No response.*
- G. *No response.*

Attachment

All hardware which make up automatic vehicles must be included in the vehicle, which would work as follows:

1. **Lateral control** This could be done using existing raised pavement markers.

Example:



2. **Distance between vehicles/stopping** Outfit each automatic vehicle with both a front and back sensor, for braking and to maintain distance.

Example:



Sensors for braking and to maintain distance.

3. **Speed control** Existing cruise control

Summation The one freeway lane normally used as an HOV lane can be used as an exclusive automatic vehicle lane. Additional lanes may be converted as necessary.

STRUCTURES

1. How would the design, construction and maintenance of elevated structures differ from conventional means assuming light weight vehicle use only?

- A. A lighter, less conservative design would be required. This lighter, less conservative design would affect the weight of the structure which would reduce seismic loadings, and the lighter live loadings would permit smaller structure depths, which in turn would reduce the wind loading on the structure. Less dead load and less live loads with less impact coupled with the reduced seismic and wind loadings will reduce the necessary column and footing designs. The cost of such a design snow balls or spirals downward.

The cost of construction would be reduced. Maintenance costs would be reduced not having the heavy truck loadings to contend with. Wind vibrations could become a design factor on longer lighter spans. This could also cause some maintenance problems. All in all, a much more cost-effective structure could be provided.

- B. The structures would be somewhat "lighter" due to the reduced live load, but the dead load of the structure would probably control the design. Construction and maintenance wouldn't change.
- C. Probably not much. Stray current protection may needed to prevent rapid corrosion of reinforcing steel.

2. What are the considerations in the design, construction and maintenance of an elevated structure that is instrumented with reference sources and power and communication distribution system?

- A. Design and construction should provide additional non-metallic conduits and pull boxes so that the system is capable of improvement or upgrading as additional technology becomes available. These conduits and pull boxes should be weatherproof to reduce maintenance. Where feasible, remote means of transmitting power (like microwave) may be considered.
- B. Location of utility placement and access. Access would be a problem on an elevated structure over a median going through the deck, closes lanes. Going through the soffit impedes the traffic below.

Corrosion due to stray current must be addressed.

- C. Stray current can accelerate corrosion.

3. **Would it be feasible to construct an elevated structure using lightweight, prefabricated sections? Could prefabricated columns be used where applicable? Is it feasible for automated machinery to be used for the assembly of such sections if the sections are designed for ease of assembly? Explain.**

- A. It would be feasible to construct an elevated structure using lightweight, prefabricated girders with a lightweight concrete deck or even a lightweight composite deck. A composite deck or even a composite girder is feasible but would take some time to fully develop in order to assure its long time, low maintenance integrity.
- B. Lightweight PC sections are feasible (although there remain questions about design parameters such as modulus of elasticity, etc., and the long term creep characteristics) but have not proven to be economic. Prefab columns have problems with connection details and adjustability especially in consideration of seismic criteria.

Automated machinery is currently used for PC segmental construction.

- C. Prefabricated structures are quite common & feasible

Structures that utilize lightweight concrete have had performance problems, so the use of lightweight concrete for the main structural section is not recommended.

Automated assembly of precast members is used but is not normally considered cost effective unless site conditions create high falsework costs.

4. **What other type of tasks might be automated to facilitate construction and maintenance of this system configuration?**

- A. A monocoque type of construction could be used for bridge girders. Within certain ranges a girder could be made longer by simply adding on another module. Kaiser engineers had a triangular bayed girder system called the unistress bridge made from aluminum -- one step further is to construct it in longitudinal modules as well as transverse modules. This structure could also be constructed of steel and even could be prestressed to reduce the structure depth and live load deflection. The automation comes in the form of shop fabrication and simple field erection.
- B. *No response.*
- C. Unknown.

5. Do you perceive any problems with retrofitting the conventional structures with reference sources?

- A. You should define "reference sources." For this exercise I will assume you mean common reference sources such as AASHTO.

Since the loading will be much less with these light vehicles, I believe that retrofitting conventional structures can probably be done utilizing common reference sources. Any new technology equipment which would have to be installed would, of course, have to have appropriate reference sources.

- B. No.

- C. Shouldn't be a problem as long as vehicle weights comply with the vehicle code.

Stray current protection may be an issue in some cases but probably not.

6. Can you identify an existing highway section as a site for a demonstration of an AHS?

- A. I cannot identify any existing highway section per se as a site for a demonstration of an AHS, but I can propose the idea of utilizing one or more diamond lanes as a starter.

- B. Harbor freeway HOV - 110.
Century freeway - 105.

- C. No.

Comments

- A. *No response.*

- B. *No response.*

- C. *No response.*

NEW TECHNOLOGY

1. What potential exists to use automated machinery for the construction of an AHS? (i.e., Could you envision using robotic equipment to assemble pre-fabricated sections for elevated structures or to install reference sources in the pavement?) Explain.

- A. The current highway construction process should also be automated. An AHS will require more precise construction methods and would definitely require an automated construction process. Current automated lane striping machines should be improved and similar technology should be developed for installing highway reference sources for lane departure warning and ultimately for lateral control of vehicles. Robotics and automated equipment for construction have a future in AHS construction in particular and all highways in general for increased safety and efficiency.
- B. Nothing to add.
- C. Yes. It is possible to utilize robotics equipment for construction and maintenance of the AHS. The use of robotics is already prevalent in the manufacturing industries (i.e., auto). Semi-robotics technologies have also been used in the transportation sector in realigning concrete median for reversible lanes or construction sites.

The IVHS technology as a whole could further the development of robotic equipment for manufacturing and maintenance of AHS and other IVHS type technologies, including prefabrication and installation of AHS components.

- D. I can envision several potential uses, which I believe will become necessities, rather than just potentials.
 - a. As you suggest, use of robotic equipment to assemble pre-fabricated sections would indeed be a good use. Additionally, robotic equipment to facilitate assembly and installation of these pre-fabricated or preformed sections. This would allow more efficient and faster assembly of sections. In areas where existing freeway sections are being retrofitted for AHS, use of robotics would make work on the right of way safer for the Caltrans and construction workers. This would also expedite installation of the AHS infrastructure to reduce lane closure of existing right of way.
 - b. Perhaps the most likely use will be in the automated installation of striping, raised markers, guidance magnets, and other (yet to be defined) AHS infrastructure related to communications, guidance, and control or automated traffic.
- E. This is construction cost consideration and may not have a great impact at this stage. Methods to reduce current construction cost are more of a priority. The robotic vision is, of course, possible. The question is feasibility and cost effectiveness, or other benefits achieved. Let's concentrate on the job we have to do and not on the use of robotics as a preordained solution.

- F. General response to all question is: AHS research development will have to evaluate the constructability and maintainability of the particular concept/application. I suspect that traditional methods of construction and maintenance will not be acceptable for most AHS concepts or vice versa (most AHS concepts will have difficulty being constructed/expanded and maintained unless new techniques are developed for construction and maintenance.).
- G. *No response.*
- H. Yes. AHMCT (Advanced Highway Maintenance and Construction Technology) equipment could be used to construct and install sensors and other related equipment. This could even be required in order to electronically "tag" reference markers as they are installed.

2. **Assume larger volumes of traffic traveling at higher speeds. Do you envision that maintenance operations need to be automated to meet the needs and demands of the traveling public in a fully automated highway system? Explain.**
- A. Ultimately, in more than twenty years, it may be practical to fully automate driving functions on dedicated portions of highway. However, it is more prudent to incrementally automate certain driving functions and use automation technology as vigilant co-pilot to provide enhanced driving safety. Autonomous Intelligent Cruise Control would probably be the first automated function to be implemented (2-5 year range). Some warning devices are already in place and more are being developed. (Greyhound system by Vorad.)
 - B. Nothing to add.
 - C. Perhaps. The degree of automation is probably dependent of the form and shape the AHS system configuration will take. If it is designed to be easily maintained, such as the Hubble Telescope, then automation is possible. If the system is complex with many system components operating at different physical locations, problem diagnosis could perhaps be computerized, but fully automated maintenance operations may well be problematic (see also Q#3).
 - D. In the early days of AHS deployment, it so far appears there will be a limited number of automated lanes with transition lanes from existing to AHS infrastructure. Any major slow down or blockage of the AHS lanes will create major problems which will be highlighted by the media as showing that AHS won't work. It will be imperative that maintenance operations on AHS infrastructure be automated from the beginning to reduce lane closures and work areas to an absolute minimum.

At present, the federally defined user services do not include a category for any type of maintenance or maintenance automation. I suggest that AVID and Caltrans need to lobby to get this important category recognized by FHWA. In light of this federal oversight, Caltrans will continue to hold and advance the leading edge of AHMCT.
 - E. Any moves in the direction of an AHS need to consider the maintainability of the system. This should be a necessary consideration in the System Definition phase of the AHS program. A properly defined AHS system may enhance maintainability. Any maintenance activities may be automated. Lane closures and openings speed reductions and vehicle path changes could be automated. Maybe many other operations could be automated. It should be assessed (not in depth design) as a factor in both the System Architecture and AHS programs.
 - F. Yes. See No. 1 above.
 - G. To meet the needs and demands of the traveling public fully automated highway systems, the time requiring the lanes to be taken out of service for maintenance should be kept to a minimum. Any work that must be done should be designed to be completed at the prevailing speed of traffic. This would have little affect on the highway capacity and should not cause unnecessary delays to motorists. This would also require that maintenance operations be conducted without workers on foot. This would have the additional benefit of significantly reducing the risk to highway workers on foot from errant vehicles.

- H. Leading question should be restated to assess the respondents vision of the new AHS AND the traffic level as well.

No, the freeway system could be completely closed during maintenance operations. i.e. similar to the I-15 in Dan Diego. However, if the system is to function in severely congested areas as will be required given funding constraints.

3. What new maintenance issues might be identified or what existing maintenance issues might be exasperated with the use of an AHS? An example of this might be increased channelization (constant wheel contact at the same location on pavement) due to lateral guidance.

- A. Maintenance of the integrity of the AHS is very important. Maintenance functions will have to be performed faster, restoring the integrity of a sensor for example could be performed at AHS speed without interrupting traffic (reduction of speed may be necessary). Inspection of the integrity of the AHS may be performed through vehicles as probes or through maintenance vehicle tracking with the traffic. Increased channelization should not be a problem. Vehicle may be traveling with tolerance of one foot or more from center.
- B. Nothing to add.
- C. Logically, maintenance issues may need to be assessed at the AHS architecture development stage, whereby currently identified or potential maintenance issues can be configured into the system design. The system should incorporate technologies, equipment and components which support ease of maintenance.

Obviously, there will be a new range of maintenance requirements associated with the AHS system itself, and that will depend on the system characteristics and maintenance concept. Types of maintenance may vary from functional maintenance (those associated with the operation of the system) to system maintenance (activities associated with system hardware and software maintenance and repairs). As far as maintenance issues resulting from AHS impacts on existing highways are concerned, those may also take different forms. For example, certain aspects of the existing system may have to be modified to facilitate AHS/IVHS efficiency. New pavement design and material may need to be developed in order to minimize channelization due to lateral guidance.

It is noteworthy that the AHS is not a mutually exclusive system, but part of interconnected subsystems which together provide the IVHS user services. Therefore, many of the construction, maintenance and operational issues are related to the larger system and must be addressed within that context.

- D. As you pointed out, channelization certainly will become an issue. A second and perhaps more important issue will be fail-safe operation of the infrastructure electronics including communications beacons, guidance equipment, and other items related to lateral and longitudinal control. The primary issue here will be to establish and maintain up time and operational status. With the AHS traffic at such close headways and such high volumes, a shutdown of the infrastructure electronics has the potential to cause or aggravate a major accident.

Other areas that may be important are establishment and maintenance of physical barriers between the existing and AHS traffic (perhaps something similar to Jersey barriers), establishment and maintenance of transition areas (entry and exit), establishment and maintenance of test/check areas for automated verification of vehicles prior to entry, emergency extrication of vehicles from the AHS with minimal interruption to current and AHS traffic flow. To my knowledge no one has addressed emergency medical or maintenance vehicles as they will be needed on the AHS system.

- E. New levels of liability might evolve with AHS. Maintenance negligence is a prime claim on a large proportion of Caltrans' lawsuits. This could be a "show stopper." How to maintain and how reliable and safe the system can be will be extremely important. Maintenance issues need to be surfaced early. Real time on-line vehicle and infrastructure diagnostics will probably be required.
- F. See No. 1 above.
- G. My biggest concern would be the guidance system. First, what maintenance will it require? Second, what effect will any surface treatments have on the guidance system? For example, if the AHS is installed on a roadway with an asphalt surface and that surface is sealed or resurfaced, how will the AHS react to that? Will the system have to be reinstalled? Third, what effect will the weather have on the AHS system? For example, the snow and ice pack over the Sierras. Would plows have to be redesigned to prevent them from damaging the AHS?
- H. It is foreseeable that additional maintenance operations will become necessary as more equipment is installed on the highway. These may be a slight reduction in some maintenance tasks such as raised pavement marker replacement.

4. Could these new or existing maintenance tasks be performed by automated or robotic equipment?

- A. Most maintenance procedures should be automated. However, safety and economics have to be considered. When evaluating automation of maintenance functions. Access to the AHS should be limited to a minimum therefore remote operation of functions is desirable. For example, landscaping, watering, garbage removal inspections/operations should be automated when economically and technically feasible. We must remember that the goal is to increase the number of vehicles per lane per hour on the highway. Thus, we must not delay such traffic with slow inefficient maintenance operations.
- B. Nothing to add.
- C. Possible. See questions #1 and #2.
- D. Yes. It seems to me that all the maintenance of the roadway must be automated to facilitate the rapid and safe repair of the structures. As I stated above, closure of lanes will lead to massive traffic jams and blockages. Especially in the "early days of AHS" any problems causing traffic jams or tie ups will be highlighted by the media and opponents of AHS and will be used to try to derail the system.

I suspect that all the electronic infrastructure will need to be highly redundant, and when a circuit or subsystem goes down, it will need to have a backup which immediately and automatically goes on line, and at the same time, notifies the maintenance folks that the down unit needs repair or replacement. ("ET Call Home?") There are several architectures of fail-safe or fail soft computer systems. There is no need to reinvent the wheel, just use them.

- E. Yes, but the key is how best to accomplish the work and not just to automate or robotize.
- F. See No. 1 above.
- G. Robotic storm patrol? Maybe. Robotic AHS guidance system maintenance? I certainly hope so.
- H. Sure.

5. Could maintenance operations take advantage of the new AHS configuration for increased safety and efficiency of maintenance tasks (i.e. use of AHS vehicle guidance and control system)? Explain.

- A. The maintenance vehicles should definitely be designed to be compatible with the AHS and use the features such as sensors, etc. - for guidance of the automated maintenance vehicles/equipment.
- B. Nothing to add.
- C. Yes. It is quite likely that by the time AHS is deployed, many of the other user services will already be in place. Maintenance operations can take advantage of not only AHS configurations such as ones mentioned above, but also other user service configurations for increased safety and efficiency of maintenance tasks.
- D. The AHS infrastructure will be able to provide a wealth of information related to traffic, including such things as volume, speed, location of bottlenecks, location of sudden slow downs and so on. If vehicles are outfitted with vision systems, they could provide information as to the location and extent of damage to the infrastructure in real-time (or nearly so) so that maintenance could be dispatched quickly while the problem is small. The AHS infrastructure could then guide maintenance personnel to the exact location of the problem within a few meters. If maintenance functions have been automated using robotics, (raised marker placement for instance) and a critical marker or series of markers is determined to be damaged, a maintenance truck could be dispatched, the infrastructure computer could slow the traffic in the area to the speed necessary for the maintenance vehicle and the repair made "on the fly" without stopping the traffic. In the worst case, the maintenance could be done in the middle of the night within 24 hours and be fixed with a minimum of interruption to traffic.
- E. See No. 4 above.
- F. See No. 1 above.
- G. If the AHS system reduces or eliminates the collisions and run-off-the-road vehicles, then we should have a safer work place.

I'm sure maintenance forces could use the system to work more efficiently. For example, a roadside vegetation control spray rig could operate by itself. There would be no need for a shadow vehicle as it sprays herbicides on the roadside. Perhaps even the spray rig itself could be self guided allowing the operator to do other things such as chemical selection.

- H. Leading question - How can maintenance take advantage of AHS technology?

I would expect that our maintenance equipment should be outfitted with the AHS sensors and control equipment to facilitate and test the system as well as improve maintenance operations.

6. How might traffic operations take advantage of AHS attributes to facilitate emergency response situations?

- A. With a fully automated system with real time control/monitoring, the TMC should be able to detect incidents immediately and issue commands to slow traffic/remote traffic to avoid cumulative traffic, etc.

Emergency response for AHS should be carefully planned. The objective if the AHS is to maximize use of space on the highway, therefore, it may not afford to have a free lane for emergency vehicles only. However, the AHS may be designed to accommodate precise maneuvers to allow passage of emergency vehicle to specific portions of the AHS.

- B. Nothing to add.
- C. IVHS technology, including AHS as a whole, is expected to improve safety through minimizing human error, new control systems, preventing or reducing the severity of injuries in accidents, and enhance traveler security in all transit modes. It could further improve emergency responses through reducing demand on emergency services and real response time. As indicated earlier, AHS must interface with other IVHS user services in order to operate properly. AHS along with other IVHS services could provide real time communication from a particular vehicle, provide vehicle location, initiate automatic emergency notification and provide in-vehicle component monitoring.
- D. Maintenance, operations, law enforcement, and emergency medical vehicles and personnel could use the AHS infrastructure to locate emergencies. The disabled vehicle, or another vehicle nearby will be able to notify the central or local computer where the problem is located, and likely some detail on the nature of the problem. This information can be relayed to the Traffic Management Center and to the Maintenance Dispatch Center for rapid response. The same AHS attributes that will allow a traveler to identify the best route will allow emergency vehicles to get to the problem. This will include identifying the best alternate routes, and programming priority routing of other vehicles to open up a route for the emergency vehicles if needed. The same information can be used for vehicles leaving the incident location trying to get to a hospital or other facility. The AHS infrastructure can be used to identify or create a route if needed.

Beyond emergency responses, AHS infrastructure will allow operations folks to monitor and predict traffic problems before they become disasters, and take advantage of rerouting both AHS and normal traffic to minimize the problems. This might even include such things as predicting traffic related to a local sports event, and rerouting through traffic to miss most of the local event traffic.

- E. Safe degradation, clear path for emergency response team, automatic incident location.
- F. See No. 1 above.
- G. *No response.*
- H. It is conceivable that some emergency response equipment is fully automated. In addition, with the system operation controlled by the "center", emergency response should be easier to locate, reach and remove by controlling the other traffic.

OTHER STATES

1. **How would conventional cross section specifications change? Explain.**
 - A. *No response.*
 - B. *No response.*
 - C. The roadway would now also contain either wires cut into slots, magnetic nails, or some other devices imbedded in the pavement. Pavement thickness would need to be greater than in conventional cross sections. In addition, the pavement design would have to take into account the above items (for longevity consideration, etc.)
2. **Could automated construction equipment be used for the installation of the reference sources (i.e. magnetic nails, passive wire, active wire, etc.) that are embedded in the pavement? Explain.**
 - A. *No response.*
 - B. *No response.*
 - C. The potential for having a totally unmanned (automate) machine is not very great. An installation vehicle could have some automated equipment such as a device to install magnetic nails, or machinery to cut a slot and install a wire automatically. However, the construction equipment probably would be manned.
3. **What potential exists to use automated machinery for construction? Could you envision using robotics to assemble pre-fabricated sections?**
 - A. *No response.*
 - B. *No response.*
 - C. The potential for using robotics for assembling prefabricated sections is not very likely. We believe that construction methods would not change that much from the present, especially in the near-term future. Some automation could be used in the installation equipment for wire or nails as discussed in Number 2.

4. **Assume larger volumes of traffic traveling at higher speeds. Do you envision that maintenance operations need to be automated to meet the needs and demands of the traveling public in a fully automated highway system? Explain.**
- A. I cannot see the maintenance operations automated. At some point, either a human body or a piece of equipment is going to have to physically occupy the roadway. This would curtail all traveling in that lane. The only alternative is to be able to make repairs at 128.7 km/h and that seems somewhat unrealistic.
 - B. Maintenance operations should be automated to insure speed and efficiency and maximized. Highest quality materials and procedures are essential. High speed and short headway will not permit maintenance to be accomplished under traffic. Automated highways will have to be designed to provide access to each lane without crossing adjacent lanes or else the system will have to be taken out of service to perform maintenance.
 - C. It would be very advantageous to automate some of the maintenance operations functions. However, traditional roadway pavement maintenance functions would be difficult to automate. At least two other opportunities exists, however:
 - a.) A probe vehicle could travel on the automated guideway to automatically determine maintenance or operations needs (roadway pavement condition, signal strength on wire, etc.).
 - b.) The intelligence buried in the roadway could also give feedback on similar maintenance and operations information.
5. **What type of tasks can be automated to facilitate the maintenance of this system configuration?**
- A. The only activity that I can think of that may be automated would be striping. Patching, sealing, overlay, may all be automated but it would still require closure of the roadway. Doing maintenance quickly would be desirable but doing it under traffic would seem very unlikely unless traffic volumes were very low.
 - B. Robotic crack filling and joint sealing, spall patching, lane marking and sweeping plus high performance materials.
 - C. As stated in Number 4, a probe vehicle could be used to determine operating characteristics, and the intelligence buried in the roadway could be used for system surveillance and checkout.

6. Could maintenance operations take advantage of the new AHS configuration for increased safety and efficiency of maintenance tasks (i.e. use of AHS vehicle guidance and control system)? Explain.

- A. It is conceivable that the guidance system could be used for speed and lateral control for certain operations, i.e., striping, overlay, sealing, etc. For patching, it is still going to require a man or machine occupying space and tamping the hole full.
- B. Yes, robotic equipment now being designed and tested as a result of SHRP could use AHS guidance and control systems.
- C. Feedback from the vehicle guidance and control system could be used to determine vehicle locations, both for use by maintenance employees to determine where other vehicles are located, and by users' vehicles to determine where maintenance vehicles and personnel are located. Also, the system should be able to automatically notify vehicles of maintenance work underway on the roadway, and then automatically control their speed.

A mix of trucks and light vehicles could make the safety problems associated with maintenance tasks more severe.

7. Could traffic operation take advantage of an AHS system configuration to facilitate emergency response situations?

- A. *No response.*
- B. Yes, could be used to automatically close lanes and control emergency response equipment.
- C. Absolutely. At least two methods could be used. The intelligence in the roadway should be able to notify a control center of any problem detected on the roadway. Also, the vehicles could be notified of problems, and the control system can either stop or slow traffic by using the intelligence in the roadway.

8. **Would the installation of reference sources embedded in the pavement affect the durability and integrity of the pavement on conventional highway lanes? Explain.**
- A. Of the reference sources cited, I would not see these to be a problem to the integrity of the pavement system as long as they were compatible with the surfacing material.
 - B. No current reference sources, sensors and wires haven't had a negative impact on pavement durability.
 - C. Any foreign item installed in the roadway would negatively affect the durability and integrity of the pavement. This problem would be worse if heavy vehicles were allowed on the automated roadway. Different or new construction methods may be able to alleviate the problem somewhat. Also, the pavement design may need to be modified.
9. **Assume that the system configuration is designed such that a designated, automated highway lane supports automated vehicles that laterally travel in the same path on the pavement. What effect might automated vehicles have on the pavement in regards to pavement degradation due to constant wheel contact at the same location (channelization)?**
- A. This could be a problem but similar one exists now. Direct tracking could be avoided by placing the centering system on different vehicles in different locations so that each would not follow in the exact track of all other vehicles.
 - B. Same path travel will tend to increase channelization. Current vehicles have varying tire and axle widths which reduce same path travel. AHS should vary travel path to avoid same path travel.
 - C. Channelization could be a problem, especially if narrow lanes were used and there was little room for side-to-side movement of vehicles. In addition, if heavy vehicles were allowed on the automated roadway, the problem could be much worse. However, if the pavement was constructed to proper standards, and only light weight vehicles allowed, this should not be a severe problem.

MISCELLANEOUS

- A. This letter is response to your questionnaire concerning the above sent to the Arkansas Highway and Transportation Department (AHTD) by AASHTO E-Mail on February 10, 1994. Please be advised that, while the concept of the Automated Highway System (AHS) is very interesting, the AHTD does not have sufficient experience in this field and those associated with it on your questionnaire (i.e. robotics, automated maintenance, etc.) to appropriately answer this inquiry.
- B. Consideration should be given to extra legal loads and vehicles that move under transportation permit over the state highway system. These extra legal vehicles and loads are longer, wider, higher and heavier than limits set forth in Section 15 of the California Vehicle Code. They should not be overlooked in any planning for automation at close headway, high speed, etc. because they will certainly run over more than one lane. Transportation permits should be involved in the study.

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16. Abstract Conventional construction and maintenance methods and procedures will not be able to support the development of an Automated Highway System (AHS). With the increasing traffic and limited capacity of the existing infrastructure, conventional construction and maintenance operations will severely impact the existing traffic problems of today unless operations are improved, developed and advanced in parallel to the development of an AHS. Survey questionnaires were prepared and distributed to selected transportation experts requesting qualitative assessments of the impact considerations that need to be addressed in terms of construction, design, maintenance, new technology, pavement, structures and traffic operations. The survey responses are summarized and discussed.			
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