Title

AHS Deployment: A Preliminary Assessment of Uncertainties

Authors

Hall, Randolph W.
Tsao, H.-S. Jacob

Publication Date

1994

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

AHS Deployment: A Preliminary Assessment of Uncertainties

Randolph W. Hall and H.-S. Jacob Tsao

California PATH Working Paper
UCB-ITS-PWP-94-02

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

JANUARY 1994

ISSN 1055-1417

AHS Deployment:
A Preliminary Assessment of Uncertainties

December, 1993

Randolph W. Hall and H.-S. Jacob Tsao
PATH Program
Institute of Transportation Studies
University of California, Berkeley

SUMMARY

This paper provides a preliminary assessment of uncertainties, both technical and institutional, associated with the deployment of Automated Highway Systems (AHS). Seven issues are addressed, concerning whether: (1) People use AHS, (2) Auto makers manufacture equipped vehicles, (3) Government builds AHS roadways, (4) Highways can evolve, (5) Interest groups do not obstruct, (6) Performance is adequate, and (7) Technology is feasible. For each issue, a table is provided that lists some of the more critical uncertainties.

INTRODUCTION

One of PATH's distinctions is its research and development program in Automated Highway Systems (AHS). AHS has the potential for a large highway capacity gain without requiring significant right-of-way acquisition. However, it is the most technology-intensive component of IVHS (Intelligent Vehicle Highway Systems), and its deployment could be costly. In this high-yield but high-risk environment, it is particularly important to identify the critical issues, technical or not, that need to be resolved to ensure timely and efficient deployment of AHS.

As one step toward this task, AHS experts were interviewed to elicit their visions for AHS, and to capture their specialized expertise with respect to the most significant risks to AHS deployment. These interviews were supplemented by a series of meetings among systems researchers from PATH, California Department of Transportation (Caltrans) and Lawrence Livermore National Laboratory, aimed at synthesizing a wide range of issues (as opposed to the interviews which, in each case, concentrated on a few issues in depth). This paper documents the findings of these meetings.

The list on AHS deployment risks will serve as an input to an ongoing study funded by the Federal Highway Administration on AHS costs and benefits. One aim of this study is to assess potential risks associated with AHS deployment, and to identify ways of overcoming these risks, We hope that an improved understanding of these risks will be valuable in prioritizing research efforts in AHS, to ensure that the major uncertainties are resolved as early as possible.

AN INFLUENCE DIAGRAM FOR AHS FEASIBILITY

The influence diagram depicted in Figure 1 (p. 3) illustrates the relationships between factors that may dictate the "feasibility" of AHS. By feasibility, we do not require that the AHS produce a net societal benefit. Instead, feasibility is defined as: "people use AHS" and "people maintain their automated vehicles **(AV).**" Without these two events, the AHS could not exist (hence, it would be "infeasible").

For feasibility to occur, other events must occur first: (1) manufacturers must sell vehicles equipped for automation, (2) government (or perhaps the private sector) must build the AHS infrastructure, and (3) users must perceive a net personal benefit from purchasing equipped vehicles. These events, in turn, depend on other factors. Moving up the diagram, government will only build and maintain an AHS if: there is sufficient support from interest groups; automation benefits are sufficient to justify the investment; and there exists a feasible plan for introducing AHS over time. Likewise, manufacturers will not sell equipped vehicles unless

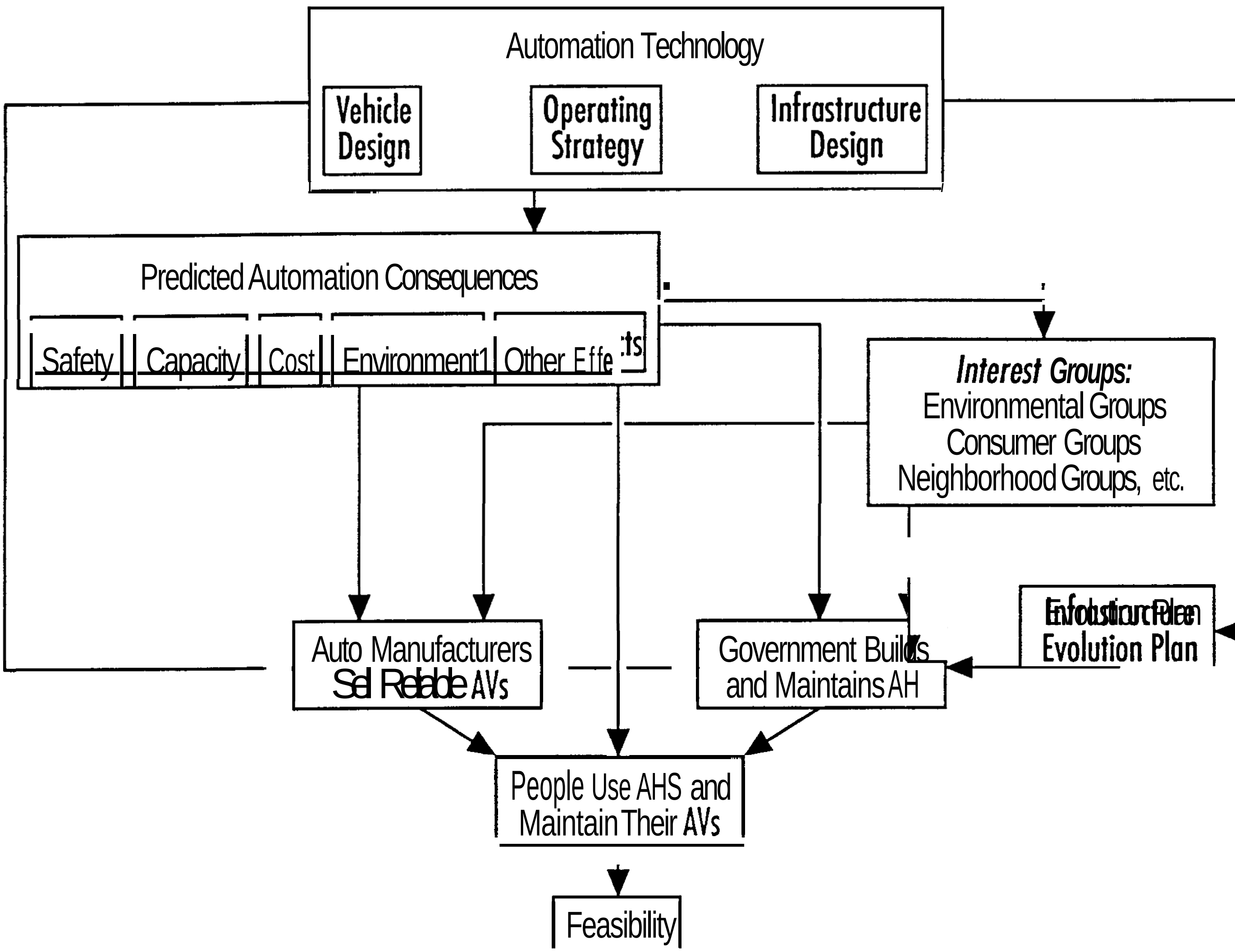

Figure 1: **AVCS** Feasibility Influence Diagram

various antecedents are satisfied, with respect to consumer demand, interest group opposition and so on. At the top of the diagram are the enabling technologies, with respect to vehicle technology, infrastructure technology and operating strategy, which must also be developed to ensure feasibility.

The significance of the diagram is that it merges the technical concerns with the non-technical concerns, illustrating that a serious breakdown at either level may make AHS infeasible,

Based on this diagram, we organized the feasibility issues into seven categories:

1. **People Use AHS**
   Given reliable vehicles and highway infrastructure, individuals must choose to purchase AHS equipped vehicles, and use these vehicles on AHS equipped roadways. People must also maintain their vehicles properly to ensure continued usage.

2. **Auto Makers Manufacture Equipped Vehicles**
   Given a feasible vehicular technology, auto manufacturers must choose to sell equipped vehicles, motivated by adequate return on investment, acceptable liability risk, adequate government investment in infrastructure, and a favorable regulatory environment.

3. **Government Builds AHS Roadways**
   Given a feasible infrastructure technology, government must choose to build AHS, based on public and industry support, favorable cost/benefit ratio, acceptable liability risk, etc.

4. **Highway Can Evolve**
   Given a feasible technology for constructing AHS, it must be possible to build the AHS within existing land-uses and right-of-way, at reasonable cost, and without unacceptable traffic disruption during construction.

5. **Interest Groups Do Not Obstruct**
   Given a feasible technology, interest groups must not obstruct AHS, out of fear that it is not a wise investment, or fear that it will harm their constituents.

6. **Performance is Adequate**
   Given a feasible technology, the AHS must provide sufficient benefits to justify the costs and impacts, in terms of congestion reduction, safety improvement, and performance improvement, without major negative consequences.

7. **Technology Feasible**
Vehicle/highway automation must be adequate to meet the rigors of full-scale deployment under a full range of operating conditions, including reliability, maintainability, etc.

FEASIBILITY ISSUES

To gain a better understanding of feasibility issues, we interviewed a wide range of specialists, reflecting expertise in many aspects of AHS. **A** major goal of the interviews was to assess which of the barriers to AHS may prove to be the most difficult to surmount, and how they might be approached. The interviews were loosely structured to allow exploration of each specialist's expertise in depth. In these interviews, we emphasized the types of barriers within (6) and (7), because these were their primary areas of expertise. To follow up the interviews, a series of meetings was held among systems researchers from PATH, Caltrans, and Lawrence Livermore National Laboratory, especially within areas (1) - *(5).*

The interviews and meetings resulted in the list of issues in Tables 1.1 — 1.7 (pp. 7-17), which correspond to the seven categories introduced in the previous section. The issues presented are not of equal priority. Boxes 1-3 in the tables can represent a degree of urgency, roughly as follows: (1) issues needing attention as part of initial research efforts, **(2)** issues needing attention as part of development efforts, and (3) issues needing attention as part of deployment efforts. While it might be said that all issues need attention now, clearly some demand earlier attention that others, either because they serve as input to other areas of work, or because their resolution is essential to eventual deployment (i.e., unless a solution is found, AHS cannot exist). Through future research, it is our goal to examine the significance of each issue with respect to the above scheme, and to identify ways for resolving the issues.

The process was interesting in several respects. Perhaps the most striking aspect was that most researchers felt that the technological challenges within their own domain would not be insurmountable. The most critical issues, in their views, typically fell outside their domain, or were otherwise related to overall system design and institutional issues. In addition, it was apparent that the concept of the overall system varied from person to person. All of this points to a need for a more integrated vision of AHS, within which research efforts could be coordinated,

CONCLUSIONS

To date, PATH research has centered on developing the enabling technologies for AHS components, and to some degree developing operating concepts and assessing impacts. These emphases are clearly appropriate for the initial stages of AHS development because they provide the foundation from which AHS feasibility will eventually be determined.

Quite independent of technological feasibility, critical issues lie ahead. It may be possible to determine in the near future whether AHS can be built on existing right-of-ways. If not, this may mean construction of facilities dedicated to automated vehicles. This may in turn affect the total design of the AHS, down to the level of sensors, actuators and communication. Overall, this study was intended to identify these issues, and provide direction toward overcoming potential barriers to AHS.

ACKNOWLEDGMENTS

The authors would like to thank Rokaya Al-Ayat, Mohamed Al-Kadri, Tony Hitchcock, Bruce Hongola, Hong Lo, Mark Miller, Bin Ran and Bobby Rao for their active participation in the systems discussions. Kwang-Soo Chang, Michael Fehling, Karl Hedrick, Tony Hitchcock, Petros Ioannou, Robert Johnston, Gordon Newell, Charles Pearson, Thomas Pollock, Masayoshi Tomizuka, Pravin Varaiya, Richard White and Wei-Bin Zhang participated in the interviews. Our appreciation goes to Steven Shladover for his comments on the paper.

This work was performed as part of the California PATH (Partners for Advanced Transit and Highways) Program of the University of California, in cooperation with the State of California, Business, Transportation and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Table 1.1

CATEGORY 1: PEOPLE USE AHS

Given reliable vehicles and infrastructure, individuals choose to use the ***AHS*** *(or purchase equipped vehicles), and they choose to maintain their vehicles properly.*

Issue No.	Issue	Evaluation		
		1	2	3
1.1	AHS is perceived as safe under actual operating conditions, accounting for inter-vehicle spacings and presence of lane barriers (if any).			
1.2	Public does not overly fear/distrust technology, due to · history or media representation of AHS safety · history of reliability of precursor technologies.			
1.3	Attitudes toward relinquishing control of vehicle must not be an obstacle.			
1.4	Vehicle purchase and maintenance cost, and any use fees, must be acceptable relative to benefits.			
1.5	Time savings on fully automated AHS should be significant.			
1.6	Maintenance, entrance inspection, transition, etc. should be convenient.			
1.7	Liability and litigation concerns must not be an obstacle.			
1.8	AHS must be attractive relative to conventional modes, both automobile and transit.			
1.9	Ride comfort and vehicle performance must equal or exceed conventional vehicles.			

Table 1.2

CATEGORY 2: AUTO MAKERS MANUFACTURE EQUIPPED VEHICLES, AND PARTICIPATE IN AHS *Given a feasible vehicular technology, auto makers must choose to manufacture AHS equipped vehicles*				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
2.1	Manufacturing tooling and production costs must be acceptable.			
2.2	Ease and cost of proper maintenance must be acceptable.			
2.3	Market potential, accounting for varying climatic conditions, traffic problems, land availability, etc., must be adequate based on expected benefits, revenues and costs.			
2.4	Component compatibility must not be a problem, due to lack of standards, or costs of imposing standards on all vehicles			
2.5	Product liability and litigation must not be an obstacle.			

Table 1.3

CATEGORY 3: GOVERNMENT BUILDS AHS ROADWAYS

Given a feasible infrastructure technology,
*government must choose to build **AHS** roadways.*

Issue No.	Issue	Evaluation		
		1	2	3
3.1	Construction/construction technology is feasible for high priority sites.			
3.2	AHS construction is cost-competitive relative to conventional roadways.			
3.3	Funds are available to extend system at acceptable pace.			
3.4	Liability and litigation are not obstacles.			
3.5	AHS is perceived as fair, relative to economic classes of drivers, relative to affected communities, and relative to regions of country.			
3.6	Enabling laws/traffic code are enacted on time.			
3.7	Roadway maintenance burden is manageable given costs and skill mix.			
3.8	Government expects vehicle industry to provide vehicles.			
3.9	Government expects vehicle industry to provide the vehicles.			

Table 1.4

CATEGORY 4: HIGHWAY CAN EVOLVE

Given a feasible technology for constructing AHS, the AHS can be built within existing land uses and right-of-way.

Issue No.	Issue	Evaluation		
		1	2	3
4.1	Conventional lanes can be retrofitted to automated lanes when needed.			
4.2	New right-of-way can be acquired when needed, either for entry/exit or for new routes.			
4.3	Initial AHS implementations, on small scale, can build momentum for later expansions.			
4.4	Benefits occur initially, even with low usage, and safety concerns do not prevent limited mixing of equipped and un-equipped vehicles.			
4.5	Vehicles can be inspected, if necessary, without consuming excessive space or time.			
4.6	Interfaces with conventional roadways do not result in major bottlenecks.			
4.7	Conventional roadways provide sufficient capacity to support access and egress from the AHS.			
4.8	Where necessary, parking at destinations can support traffic volumes.			
4.9	Standards are enacted on time.			

Table 1.5

Issue No.	Issue	Evaluation		
		1	2	3
CATEGORY 5: INTEREST GROUPS DO NOT OBSTRUCT *Given a feasible technology, interest groups do not oppose **AHS** because it is not perceived as harmful to their constituents.*				
5.1	Environmental impacts (if any), with respect to land use, pollution, noise, and aesthetics are acceptable relative to alternatives.			
5.2	Concerns that **AHS** might induce new traffic are mitigated.			
5.3	**AHS** is not perceived as inequitable, with respect to economic classes, neighborhoods, regions of the country, etc.			
5.4	**AHS** is supported by affected industries, such as aerospace, vehicle manufacturing, construction.			
5.5	**AHS** is not opposed due to general opposition to "big government", or opposed due to taxes needed to support public infrastructure.			

Table 1.6a

CATEGORY 6: PERFORMANCE IS ADEQUATE

*Given a feasible technology, the **AHS** provides sufficient benefits to justify the costs and any negative impacts.*

Subcategory: CAPACITY GAIN

Issue No.	Issue	Evaluation		
		1	2	3
6.1	There must be sufficient need for AHS capacity gains, based on traffic generation rates, o-d patterns and trip lengths (i.e., capacity gains must translate into travel time savings).			
6.2	Close headway driving must be achievable in field operating conditions, providing stable traffic flow in high volume.			
6.3	Vehicle or system failures must not disrupt traffic and make travel times unreliable to an unacceptable extent.			
6.4	Collisions must not result in unacceptable delays, and the system must have the means for quickly removing accidents.			
6.5	Automated highway-to-highway interchanges should not prove to be excessively expensive, in which case conventional highway-to-highway interchanges could become bottlenecks.			
6.6	Origin-destination patterns and trip length distributions should be consistent with AHS design, if exits and entrances need to be spaced far apart.			
6.7	Vehicles must be able to exit at desired locations with high probability.			
6.8	In mixed conventional/automated highways, traffic must be capable of accessing the automated lanes through the manual traffic, and transition lanes, in sufficient volume to support the capacity.			
6.9	Access roadways and exit/entrance ramps must have sufficient capacity to support the **AHS.**			
6.10	Parking must be available to support **AHS** traffic volumes.			
6.11	Capacity gains in automated lanes must significantly exceed capacity losses (if any) in non-automated lanes.			
6.12	If barriers are needed to separate lanes, they must not reduce capacity excessively, due to reducing capacity for lane changes, or due to obstructing accident clearance.			

Table 1.6b

Subcategory: COMFORT AND PERFORMANCE				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
6.12	**AHS** provides a smooth ride in a range of operating conditions (e.g., no jerk, fast deceleration, etc.)			
6.13	People find the experience of automated driving comfortable and relaxing, including the transitions between manual and automated driving.			
6.14	Driving in **AHS** must give the appearance of safety, by providing adequate cues to travelers, and providing a pleasurable driving experience.			

Table 1.6c

Subcategory: SAFETY (vehicles)				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
6.15	Vehicle must be sufficiently reliable and fault tolerant that hazardous failures occur rarely, if ever.			
6.16	There must be assurance that safety critical aspects of vehicles are adequately maintained.			
6.17	Control software must be reliable under all conceivable operating conditions.			
Subcategory: SAFETY (roadside components)				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
6.18	Roadside components must be inspectable, especially in remote locations and under adverse conditions.			
6.19	Roadside components must be sufficiently reliable, maintainable and fault tolerant that hazardous failures occur rarely, if ever.			

Table 1.6d

Subcategory: SAFETY (human factors)				
Issue No.	Issue	Evaluation		
			2	3
6.20	Unequipped vehicles must be prevented from entering automated lanes (intentional or not) and causing collisions.			
6.21	The system must be secure from sabotage, both physically (e.g., vandalism on the roadway), and in its control systems (e.g., software viruses).			
6.22	Drivers must be capable of safely and reliably resuming manual control upon exiting the **AHS.**			

Subcategory: SAFETY (after a collision)				
Issue No.	Issue	Evaluation		
		1	2	3
6.23	Collisions, if they occur, must not lead to catastrophic chain-reactions.			
6.24	Emergency equipment must be capable of reaching the scene of an accident, even if lanes are separated by barriers. People must be not be endangered in the aftermath of a collision, due to inability to exit to a safe location.			

Table 1.7a

CATEGORY 7: TECHNOLOGY IS FEASIBLE				
Vehicle/highway automation is adequate to meet the rigors offill-scale deployment.				
Subcategory: CONTROL ALGORITHMS AND ACTUATORS				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
7.1	Control algorithms must be responsive to variations in external state (grade, curve, pavement friction, road wear/conditions, climate), especially with respect to uneven pavement friction and wind gusts.			
7.2	Control algorithms must be responsive to variations in own state (tires, brake wear, weight, engine performance).			
7.3	Control algorithms must be responsive to fault conditions, especially tire blow outs, and intrusions of objects or people into path of travel.			
7.4	Brake, engine and steering actuators must be reliable and safe under a wide range of operating conditions.			

Subcategory: COMMUNICATION SYSTEMS MUST PROVIDE				
Issue No.	**Issue**	**Evaluation**		
		1 1	**1 2**	**1 3**
7.5	Assurance that interference does not destroy, corrupt or unduly delay messages.			
7.6	Accurate identification of surrounding vehicles.			
7.7	Assurance that messages are sent to/from the correct vehicles.			
7.8	Adequate speed to support control algorithms.			
7.9	Sufficient spectrum to support data traffic/safety critical messages.			

Table 1.7b

Subcategory: SENSORS MUST PROVIDE				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
7.10	Ability to determine vehicle's own position.			
7.11	Ability to see sufficiently far ahead within a lane.			
7.12	Ability to see sufficient far ahead, to the side and behind in adjacent lanes (as well as an ability to distinguish lanes from each other).			
7.13	Ability to sense a vehicle's own state, and an ability to sense the external state.			

Subcategory: OTHERS				
Issue No.	**Issue**	**Evaluation**		
		1	**2**	**3**
7.14	Inspection must be adequate and feasible, given space, capacity and cost constraints.			
7.15	Failures of safety critical systems must be detectable instantly (if not before-hand).			
7.16	System must be capable of responding to failures of safety critical system.			