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# STUDY AND ANALYSIS OF AUTOMATED HIGHWAY SYSTEM

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## Abstract

A combination of market forces, cost constraints, and other factors necessitate incremental evo-lution of a fully automated highway system (AHS) rather than instantaneous deployment. Thus, an understanding of the interdependencies among required AHS functional capabilities is essen-tial for planning. This paper proposes a set of three AHS functional evolution reference models that include essential as well as supplemental functions. The reference models include lateral motion handling, longitudinal motion handling, obstacle handling, and selected infrastructure support functions. This family of three models is used to present the needs of baseline autono-mous tactical vehicle operation, the benefits of adding inter-vehicle communications, and the benefits of adding infrastructure support. The reference models reveal a critical need for vehicle motion prediction capability, and suggest that both communications and infrastructure support are beneficial but not mandatory for achieving an AHS. Furthermore, there appear to be a num-ber of safety and efficiency benefits that can be realized with only partial automation and in some cases no automation. These results could help set priorities and guide strategies for incremental introduction of AHS technology into vehicles and roadways.

***Keywords:*** *AHS functional evolution; incremental deployment.*

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## 1. Introduction

The idea of automated driving dates back to almost 50 years ago when General Motors (GM) presented a vision of ―driverless‖ vehicles under automated control at the 1939 World fairs in New York. In the 1950's research by industrial organizations conceptualized auto-mated vehicles controlled by mechanical systems and radio controls. After the first appearance of the computers in the 1960's, researchers began to consider the potential use of computers to provide lateral and longitudinal control and traffic management. The fully auto-mated highway concept was initially examined by GM with sponsorship from the US department of Transportation (DOT) in the late1970's. During these times, focus was laid on automated vehicles on a highway as computers were not powerful enough to consider a complete fully automated highway system. Advances in the computing technologies, micro-electronics and sensors in the 1980's provoked commercial interest in the technologies that might enhance driver capability and perception and both private and public researchers examined partially automated products and services. Among others, the University of California Partners in Advanced Transport and Highways (PATH) has carried out significant research and development in the field of highway automation since the 1980's. As various transportation technologies emerged that could assist driving on one hand and also traffic efficiency on the other, interest in fully automated driving or integrated auto- highway technologies grew once again.

## 2. Major AHS Goals

The AHS program is designed to influence how and when vehicle-highway automation will be introduced. AHS deployments will be tailored to meet the needs of public, commercial, transit, and individual travelers in rural and urban communities. The major goals are to:

1. **Improve safety by significantly reducing: -**
   - Fatalities.
   - Personal injury.
   - Pain and suffering.
   - Anxiety and stress of driving.

2. **Save money and optimize investment by: -**
   - Maximizing efficiency of the existing infrastructure investment.
   - Integrating other ITS services and architecture to achieve smooth traffic flow.
   - Using available and near-term applied technology to avoid costs of conventional highway build-out.
   - Developing affordable equipment, vehicles, infrastructure, operations, maintenance, and user fees.
   - Closing the gap on predicted infrastructure needs.
   - Using public/private partnerships for shared risk; using the National AHS Consortium as a global focal point to influence foreign deployment efforts.
   - Reducing fuel consumption and costs, maintenance, wear-and-tear, labor costs, insurance costs, and property damage.

3. **Improve accessibility and mobility by: -**
   - Improving employee on-time performance, resulting in a more effective work force.
   - Facilitating "just-in-time" deliveries.
   - Improving public transportation service, increasing customer access, and expanding service levels, resulting in increased revenue, reduced costs, and reduced accidents.

- Achieving a smooth traffic flow, reducing delays, travel times, travel time variability, and driver stress.
- Making driving more accessible to less able drivers.

4. **Improve environmental efficiencies by: -**
   - Reducing emissions per vehicle-mile travelled.
   - Providing a solid base for reliable, lower cost transit.
   - Providing an efficient base for electric-powered vehicles and alternative fuel vehicles.

5. **Create jobs by: -**
   - Providing a stronger national economy and increasing global competitiveness.
   - Increasing jobs in research and development and in early ITS deployment.
   - Facilitating technology transfer (e.g., from military to civilian use).
   - Creating new U.S. automotive products and new technology-based industry to compete in the international marketplace e.

Figure 1. A concept drawing of an Automated Highway System with dedicated lanes in the centre of the highway

## 3. Methodology

As shown in Figure 1, a driver electing to use such an automated highway might first pass through a validation lane, similar to today's high-occupancy-vehicle (HOV) or carpooling lanes. The system would then determine if the car will function correctly in an automated mode, establish its destination, and deduct any tolls from the driver's credit account. Improperly operating vehicles would be diverted to manual lanes. The driver would then steer into a merging area, and the car would be guided through a gate onto an automated lane. An automatic control system would coordinate the movement of newly entering and existing traffic. Once travelling in auto-mated mode, the driver could relax until the turnoff. The reverse process would take the vehicle off the highway. At this point, the system would need to check whether the driver could retake control, then take appropriate action if the driver were asleep, sick, or even dead.

The alternative to this kind of dedicated lane system is a mixed traffic system, in which automat-ed and non-automated vehicles would share the roadway. This approach requires more-extensive modifications to the highway infrastructure, but would provide the biggest payoff in terms of capacity increase.

In fact, a spectrum of approaches can be envisioned for highway automation systems in which the degree of each vehicle's autonomy varies. On one end of the range would be fully independent or "free-agent" vehicles with their own proximity sensors that would enable vehicles to stop safely even if the vehicle ahead were to apply the brakes suddenly. In the middle would be vehicles that could adapt to various levels of cooperation with other vehicles (platooning). At the other end would be systems that rely to a lesser or greater degree on the highway infrastructure for automated support. In general, however, most of the technology would be installed in the car.

## 4. The System Concept and Technologies

Concepts of Automated Highway System (AHS) can be classified into two groups, partially automated systems and fully automated systems, depending on the extent of the automation. Partially automated systems include notification and warning systems, temporary emergency controls and continuous partial controls, which take limited control of the vehicle in emergency situations. They automate certain routine parts of driving but rely on manual control for most driving functions. Fully automated driving would let drivers be totally disengaged from all driving tasks.

**The Five Concept Families**

- Independent Vehicle Concept: This concept puts a smart vehicle in the existing infra-structure. In-vehicle technology lets the vehicle operate automatically with on-board sensors and computers. The vehicle can use data from roadside systems but does not depend on infrastructure support.
- Cooperative Concept: This concept lets smart vehicles communicate with each other, although not with the infrastructure. With on-board radar, vision, and other sensors, these AHS-equipped vehicles will be able to

communicate with each other and coordinate their driving operations, thereby achieving best throughput and safety.

- Infrastructure-Supported Concept: A smart infrastructure can greatly improve the quality of AHS services and better integrate AHS with local transportation networks. This concept envisions automated vehicles in dedicated lanes using global information and two-way communication with the smart infrastructure to support vehicle decision-making and operation.
- Infrastructure-Assisted Concept: In this concept, the automated roadside system provides inter-vehicle coordination during entry, exit, merging, and emergencies. This concept may provide the greatest throughput benefit; it also may require the greatest civil infrastructure investment.
- Adaptable Concept: This concept acknowledges the fact that AHS implementation will vary by locality. It envisions the development of a wide range of compatible standards that leave as many of the specific architecture. The National Automated Highway System Consortium (NAHSC) defined several alternative AHS concepts, from cooperative to fully automated, depending on the degree to which vehicles and infrastructure work together as listed above.

### Current Technologies

While current vehicles use new technologies mostly for safety or driver convenience, e.g., air bags, antilock brakes, adaptive cruise control, power steering, the vehicles on an AHS system would require much more new technology that communicates with the roadway. In the simplest forms of AHS these would focus on the detection of other vehicles and obstacles. Technologies that already do this to some extents are beginning to be added to luxury vehicles or are sometimes an option that can be selected by the consumer; e.g., collision warning systems. Other technologies that would be precursors to the communications technologies in an AHS system are also being introduced; these include navigation assistance systems, traveler information systems, and vehicle locator systems. Their acceptance in the market is taken as an indicator of eventual consumer acceptance of the broader AHS concept.

## 5. Control Design of An Automated Highway System

The Control design of an Automated Highway system can be looked upon the basis of a 5-layer theory which together comprise the two systems viz. the On- board Vehicle System and the Roadside System. The control design is explained with the aid of the Figure 2:

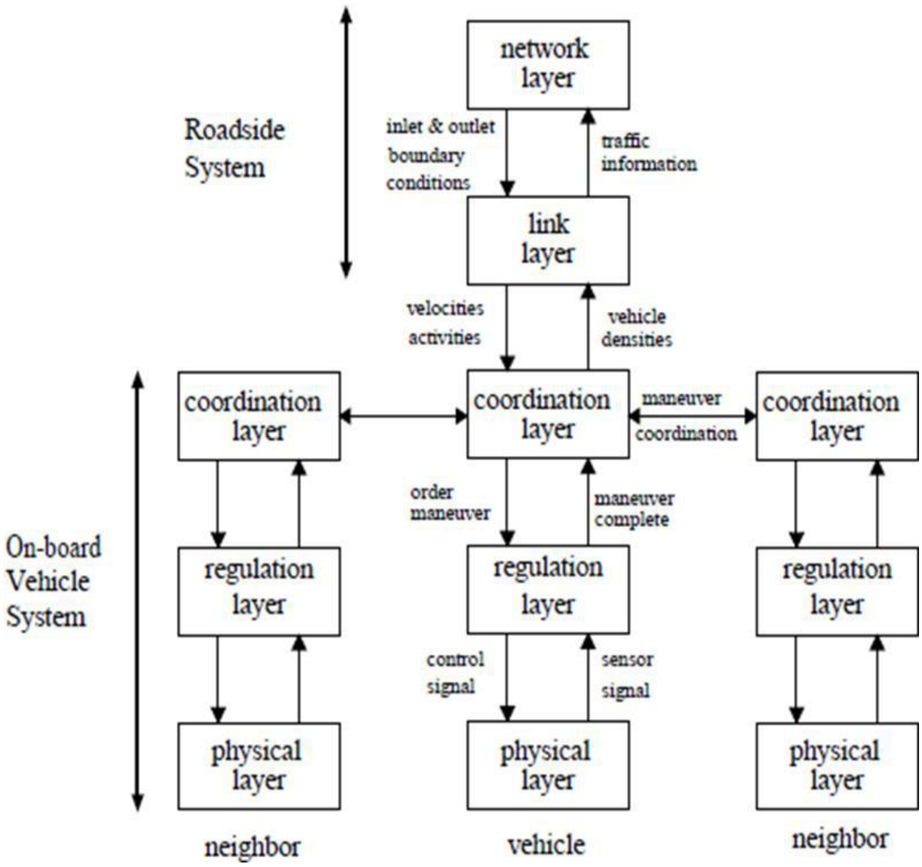


Figure 2. The Control Design of an Automated Highway System

## 6. Potential Benefits

Researchers have attempted to estimate benefits that might accrue from the implementation of auto-mated highway systems. Table 2 summarizes potential benefits. Many of the benefits shown in the table are fairly speculative; the systems they would depend upon are not yet in existence and there is no clear evidence that the system can produce the following benefits in reality.

It is anticipated that automated highway and related advanced vehicle control and safety technologies would significantly reduce traffic congestion and enhance safety in highway driving. This in turn would potentially cut travel time, and therefore, driving would be more predictable and reliable. The Mobility 2000 report, sponsored by the Texas Transportation Institute, projected that collision prevention systems could reduce accidents by 70 percent or 90 percent on fully automated highways.

Research focused on collision prevention systems has estimated possible savings in a relatively short period of time. For example, collision avoidance systems have been estimated to have the potential to reduce annual loss of life on U.S. roads by 50 percent by 2020. In addition, pre-liminary National Highway Traffic Safety Administration estimates show that rear-ends, lane-change, and roadway-departure crash-avoidance systems have the potential to reduce crashes by one-sixth, or about 1.2 million crashes a year.

## 7. Literature Survey

In order to deploy AHS capabilities, the uncertainties in the research and development of new technology must be managed well. Additionally, it is impractical to introduce fully automated vehicles on all highways instantaneously. Incremental deployment, then, is a significant issue, and several alternative strategies have been proposed. One strategy advocates the deployment of fully automated vehicles on dedicated lanes, but restricts the deployment to heavily used roadway segments equipped with special-purpose AHS guidance infrastructure. (1) Another strategy is to introduce AHS capabilities onto mass transit vehicles for use on existing High Occupancy Vehicle (HOV) lanes, subject to the supervision of a safety driver. A third general strategy involves gradually increasing the degree of automation of new and refitted vehicles over time, with both AHS vehicles and manually driven vehicles sharing essentially all interstate highways. This paper does not assume that any one of the above deployment strategies will be implemented. Rather, it presents the set of functions and sequencing constraints that are likely to be involved in deploying an AHS. Whichever deployment strategy is used, the system will need to contain some subset of the reference models' functionality to be considered a partial AHS. And, no matter the deployment strategy selected, substantially all of the functions will need to be implemented to achieve a complete AHS. This paper begins by presenting the baseline functional evolution reference model of an autonomous robotic vehicle, assuming that inter-vehicle communications are not universally available. An expanded reference model is then presented that includes the use of inter-vehicle communications, and is used to illustrate functions that are enhanced or enabled for the first time. Finally, a fully elaborated reference model is presented that adds Communications with roadside intelligence (highway infrastructure support), enhancing and enabling even more functions.

## 8. Conclusion

Automated Highway Systems brings major transportation benefits in terms of safety, efficiency, affordability and usability, and environment in order to achieve its development goals.

A key feature of the control design architecture is the separation of the various control functions into distinct layers with well-defined interfaces. Each layer is then designed with its own model that is suited to the functions for which it is responsible. The models at the various layers are different not only in terms of their formal structure (ranging from differential equations to state machines to static graphs), but also in the entities that have a role in them.

The AHS is a complex large-scale control system, whose design required advances in sensor, actuator, and communication technologies (not discussed here) and in techniques of control system synthesis and analysis. It is a measure of the advanced state of the art that these techniques have reached a stage that they could be successfully used in the AHS project.

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