Analyzing the Development and Potential Benefits of Automated Highway Systems: From Concept to Reality

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Abstract- Market forces, cost limits, and other factors require the gradual development of a fully automated highway system (AHS) instead of immediate deployment. Understanding how various AHS functions depend on each other is crucial for effective planning. This paper presents three AHS functional evolution reference models that include both essential and additional functions. These models include lateral motion handling, longitudinal motion handling, obstacle handling, and selected infrastructure support functions. The three models help illustrate the basic needs of autonomous tactical vehicle operation, the advantages of intervehicle communication, and the benefits of infrastructure support. The models highlight the critical requirements for vehicle motion prediction and suggest that while communication and infrastructure support are helpful, they are not essential for a complete AHS. There are also several safety and efficiency gains possible with partial automation or even no automation. These findings can guide priorities and strategies for gradually introducing AHS technology into vehicles and roadways.

Key Words: Automated highway systems, Vehicle motion prediction, Intervehicle communication, Infrastructure support, Intelligent Transportation System

1. INTRODUCTION

The concept of automated driving has been in use for approximately 50 years. General Motors (GM) showcased "driverless" vehicles controlled by automation at the 1939 World Fair in New York. During the 1950s, industrial research explored automated vehicles controlled by mechanical systems and radio controls. In the 1960s, with the introduction of computers, researchers began examining how these devices could provide control over driving and traffic management. GM, with backing from the US Department of Transportation (DOT), first examined the fully automated highway concept in the late 1970s. At that time, the focus was on automated vehicles on highways, because computers were not sufficiently advanced for a complete AHS. Advances in computing, microelectronics, and sensors in the 1980s sparked commercial interest in technologies that could enhance driver ability and awareness. Both private and public researchers have started to explore partly automated products and services. The University of California Partners in Advanced Transport and Highways (PATH) has made significant strides in highway automation research since the 1980s. As various transportation technologies have emerged to aid driving and improve traffic efficiency, interest in fully automated driving and integrated auto highway technologies has resurfaced.

Major AHS Goals

The AHS program aims to shape how and when vehicle-highway automation will be introduced. AHS deployments focus on the needs of public, commercial, transit, and individual travelers in both rural and urban areas. The main goals are to:

Improve safety by significantly reducing

- Fatalities.
- Personal injury.
- Pain and suffering.
- Driving-related anxiety and stress

Save money and optimize investments by

- Maximizing the efficiency of the existing infrastructure.
- Integrating other Intelligent Transportation System (ITS) services to ensure smooth traffic flow.
- Using currently available technology to avoid the costs associated with building new highways.
- Developing affordable equipment, vehicles, infrastructure, operations, maintenance, and user fees.
- Addressing predicted infrastructure needs.
- Forming public/private partnerships to share risks and using the National AHS Consortium as a global focal point to influence overseas deployment efforts.
- Reducing fuel consumption, maintenance costs, wear and tear, labor expenses, insurance rates, and property damage.

Improve accessibility and mobility by

- Enhancing employee punctuality, leading to a more effective workforce.
- Supporting "just-in-time" deliveries.
- Enhancing public transportation services, increasing customer access, and expanding service levels, which results in higher revenue, lower costs, and fewer accidents.
- Creating smoother traffic flow and reducing delays, travel time, variability, and driver stress.
- Making driving easier for less capable drivers.

Improve environmental efficiency by

- Reducing emissions per vehicle mile traveled.
- Supporting reliable, low-cost transit systems.
- Creating efficient foundations for electric and alternative fuel vehicles.

Create jobs by

- Strengthening the national economy and boosting global competitiveness.
- Generating jobs in R&D and early ITS deployment.
- Facilitating technology transfer, for example, from military to civilian use.

Developing new U.S. automotive products and technology-focused industries to compete globally.

Fig -1: Concept drawing of an Automated Highway System with dedicated lanes in the center of the highway.

2. LITERATURE REVIEW

To deploy AHS capabilities, it is necessary to manage uncertainties in the research and development of new technologies. It is also impractical to roll out fully automated vehicles across all highways simultaneously. Therefore, incremental deployment is a key issue, and several strategies have been suggested. One strategy recommends deploying fully automated vehicles on dedicated lanes that are limited to frequently used road sections with a specific AHS guidance infrastructure. Another strategy involves introducing AHS capabilities in mass transit vehicles using existing high-occupancy vehicle (HOV) lanes with a safety driver present. A third general approach suggests gradually increasing automation levels in both new and retrofitted vehicles over time, allowing AHS and manually driven vehicles to share most interstate highways. This study does not assume that any single deployment strategy will be adopted. Instead, it presents a set of functions and sequencing constraints that are likely to be involved in establishing an AHS. Regardless of the chosen deployment method, the system must incorporate part of the functions outlined in the reference models to qualify as partial AHS. To achieve a complete AHS, most functions must be implemented. This study begins with a basic functional evolution reference model for an autonomous robotic vehicle, assuming that inter-vehicle communications are not universally available. An expanded reference model that includes inter-vehicle communications and demonstrates new or enhanced functions was then introduced. Finally, a detailed reference model that adds communication with roadside intelligence (highway infrastructure support), further enhancing and enabling additional functions, was presented.

3. RESEARCH METHODOLOGY

As, as shown in figure 1, a driver choosing to use an automated highway would first go through a validation lane, similar to today's high-occupancy-vehicle (HOV) or carpool lanes. The system checks if the vehicle can operate correctly in automated mode, establish its destination, and deduct any tolls from the driver's account. Vehicles that do not function properly are redirected to manual lanes. The driver then steers into a merging area, and the car is guided through a gate onto an automated lane. An automatic control system manages the movement of both new entrants and existing traffic. Once in the automated mode, the driver could relax until the exit. The reverse process brings the vehicle off the highway. At this point, the system verifies whether the driver can take back control and act if the driver is asleep, sick, or incapacitated.

An alternative to this dedicated lane system is a mixed traffic setup, in which automated and non-automated vehicles share the same roadway. This approach requires more extensive modifications to highway infrastructure but offers greater benefits in terms of increased capacity.

A range of methods can be envisioned for highway automation systems, where the level of each vehicle's autonomy varies. One end feature fully independent vehicle with their own sensors, enabling them to stop safely even if the vehicle ahead brakes suddenly. The middle includes vehicles that can adapt to different levels of cooperation (such as platooning). The other end comprises systems that depend on highway infrastructure for automated support. However, most of the technology is typically found in vehicles.

System Concept and Technologies

Automated Highway System (AHS) concepts fall into two groups: partially automated systems and fully automated systems, based on the level of automation. Partially automated systems include notification and warning systems, temporary emergency controls, and continuous partial controls, which take limited control of vehicles during emergencies. They automate routine driving tasks while requiring manual control for most functions. Fully automated driving allows drivers to be entirely disengaged from all driving tasks.

The Five Concept Families

- **Independent Vehicle Concept:** This idea uses a smart vehicle within the existing infrastructure. In-vehicle technology allows automatic operation using onboard sensors and computers. The vehicle can access data from roadside systems but does not depend on infrastructure support.
- **Cooperative Concept:** This system enables smart vehicles to communicate with each other, but not necessarily with infrastructure. With onboard radar, cameras, and other sensors, AHS-equipped vehicles can coordinate their maneuvers to maximize throughput and safety.
- **Infrastructure-Supported Concept:** Smart infrastructure can significantly enhance AHS services and better integrate AHS with local transportation networks. This concept includes automated vehicles in dedicated lanes that use global information and two-way communication with smart infrastructure for decision-making and operation.
- **Infrastructure-Assisted Concept:** Here roadside automated system provides inter-vehicle coordination during entry, exit, merging, and emergencies. This idea may offer substantial throughput benefits but may also demand considerable investment in civil infrastructure.
- **Adaptable Concept:** This concept recognizes that the AHS implementation will differ by location. It envisions a range of compatible standards that retain flexibility in a specific architecture. The National Automated Highway System Consortium (NAHSC) has outlined several alternative AHS concepts, from cooperative to fully automated systems, based on how closely vehicles and infrastructure interact.

Current Technologies

Today's vehicles mainly use new technologies for safety or driver convenience, such as airbags, antilock brakes, adaptive cruise control, and power steering. In contrast, vehicles within an AHS would require new technology that communicates with the roadway. The simplest forms of AHS would focus on detecting other vehicles and obstacles. Some technologies that perform these functions are starting to appear in luxury vehicles, or they are options consumers can choose, such as collision warning systems. Other technologies that could be precursors to the communications needed in an AHS include navigation assistance, traveller information, and vehicle locator systems. Their growing acceptance in the market suggests eventual consumer acceptance of the broader AHS concept.

Control Design of an Automated Highway System

Control design for an Automated Highway System can be viewed through a five-layer theory, which consists of the onboard Vehicle System and the Roadside System. The control design is illustrated in figure 2.

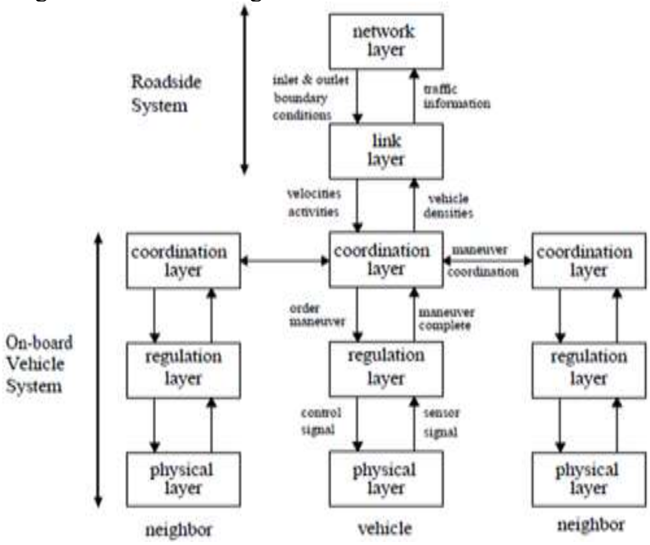

Fig -2: The Control Design of an Automated Highway System

4. CONCLUSION

The development goals include major transportation benefits that Automated Highway Systems bring in terms of safety, efficiency, affordability and usability, and environment. One of the salient features of the control design architecture described in this text is the organization of the various control functions into clearly distinguished layers, each with well-defined interfaces to the other layers. Each layer is then designed separately, beginning with a model that is appropriate for the functions assigned to it. The models at the various layers are distinct not only in their formal structure, ranging from differential equations and state machines to static graphs, but also in the entities that take part in them.

The AHS is a complicated 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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