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# Automated Highway System

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## Abstract

***A combination of market forces, cost constraints, and other factors necessitate incremental evolution of a fullyautomated highway system (AHS) rather than instantaneous deployment. Thus, an understanding of the interdependencies among required AHS functional capabilities is essential 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 autonomous 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 number 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***

## I. INTRODUCTION

For many years, scientists and engineers have envisioned building an automated highway system (AHS) to increase both the safety and efficiency of the nation's highways. In such a system, the vehicles become driving robots, capable of sensing and reacting to the surrounding environment while the driver is free to do other tasks.

Automating the vehicle has significant potential advantages: it can reduce accidents caused by driver error and can potentially increase traffic-carrying capacity and fuel economy by eliminating human driver inefficiencies. Automating the vehicle also presents difficulties: shifts in legal liability, issues of technical feasibility, and questions of political and social acceptance make the design of an AHS highly constrained, and often subject to heated debate.

There is not yet consensus on exactly what policies and configurations will be used in the operation of a fully deployed AHS. However, it is clear that an automated system will require a number of common functions such as the ability to stay in a traffic lane and to avoid collisions. Furthermore, a number of cost, technical, social, and customer constraints make it seem likely that any deployment of AHS will need to be an incremental one, as opposed to a fielding of a completely automated system from the beginning (National Automated Highway System Consortium StakeholderWorkshop #3, Minneapolis Minnesota, September 18-20, 1996, unpublished).

"Figure 1. Automated Driving System"

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## II. PREVIOUS WORK

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[2].

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 [3]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.

These three reference models illustrate important technical dependencies, highlight the effects of communication and infrastructure support on the deployment of autonomous vehicle systems, and can be used as a roadmap for tracing the development and potential usage of the functions inherent to an AHS.

"Figure 2. Automated Highway System (San Diego CA.)"

## III. FUNCTIONAL EVOLUTION

The evolution of the AHS is broken into three diagrammatic reference models: vehicle automation, the addition of inter-vehicle communications, and the addition of infrastructure support. This is done to delineate the evolutionary linkages among functions beginning with the vehicle itself and then adding system-wide applications. This delineation does not suggest that complete vehicle automation must come before communications or infrastructure based systems, but rather is used to separate development issues and clearly define how the addition of system-wide functions eases (and does not ease) the development of core vehicle systems.

Each of these reference models is further segregated by three functional categories: lateral motional handling, longitudinal motion handling, and obstacle handling. The last reference model adds a fourth category, infrastructure support, in which roadside-based assistance systems are presented. Note that these categories are deliberately chosen to separate technically relevant deployment functions. Lateral and longitudinal motion consider vehicle automation in each of these domains while also handling the effects of surrounding vehicles.

Obstacle handling is separated from the core of the vehicle maneuvering functions because of the unique technical issues surrounding obstacle detection and vehicle response. Infrastructure assistance provides unique capabilities that are separate from the basic automation of the vehicle itself.

The three diagrammatic reference models also depict two important relationships: functional dependencies, and functional beneficiaries. In each of these diagrams, the presence of a solid arrow from one function to the next indicates a functional dependency, where the first function must be technically viable for the next function to be. (This is not to say that the first function must be marketable; this is a separate issue.) For example, lane departure warning cannot be achieved without first being able to detect the lane boundaries. A solid arrow therefore links the two functions.

A dashed arrow indicates a functional beneficiary, where the technical development of the first function provides some benefit to that of the second, however the viability of the first is not required for the second to work. For example, the technologies developed for vehicle and vehicle motion detection will likely speed the development of obstacle detection and relevance determination; the unique issues associated with obstacle handling require a separate development effort however, that is not directly linked to vehicle detection.

What is important to note is how these arrows change from one diagram to the next: the addition of communications and infrastructure-based systems alleviates the technical development of vehicle-based systems in some cases yet in others provides little benefit. This provides useful insight into where the larger AHS system can make the in-

### 3.1. Baseline Reference Model: Vehicle Automation

The baseline reference model presents the evolution of vehicle automation capabilities in terms of lateral motion handling, longitudinal motion handling, and obstacle handling. Within each of these categories, Figure 3 shows the key technical functions of an AHS and their dependencies. This diagram presents the core in-vehicle functions that rely neither on inter-vehicle communication nor on the infrastructure for any support in autonomous operations.

#### 3.1.1. Lateral Motion Handling

The lateral (side-to-side) motion of the vehicle has a number of different functions, from vehicle-centric maneuvers such as lane keeping to those involving merging in heavy traffic. First, if the vehicle is to stay within the lane, it needs to know where the lane boundaries are. Lane detection is currently achieved through a number of different technologies, including a vision system(5), magnetic nails buried in the roadway which are then sensed by the vehicle(6), or a radar-reflective stripe (unpublished work at Ohio State University).

With the advent of lane detection capability, the system can then detect where it is within the lane, leading to lane departure warnings when a vehicle strays out of the lane unintentionally. This is an attractive function to have available for incremental deployment as 31% of all highway fatalities are a result of single-vehicle, run-off-road accidents.(7) Marketable systems might be in the form of warnings which alert the driver when a lane change is attempted without prior activation of a turn signal, or might involve a driver based model that adapts to the characteristic driving patterns of the driver.

“Figure 5. Automated Highway System (Los Angeles)”

#### 3.1.2. Longitudinal Motion Handling

The longitudinal (front-to-back) motion of the vehicle also has a variety of functions which range from simplistic in-vehicle handling to tactical driving within a congested traffic scene. Speed keeping is the most

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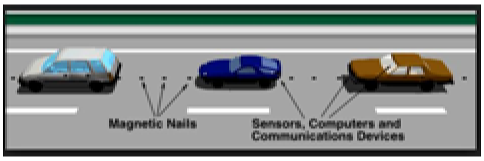
elementary function within this category, involving the maintenance of a constant travel speed. It is widely deployed in the form of "cruise control." Headway keeping, also known as adaptive cruise control, is a function which adapts the speed of the vehicle to match that of a lead vehicle while maintaining a safe distance. Headway keeping is currently being deployed on a limited scale in foreign markets.

Avoidance via hard braking is where the vehicle brakes to avoid an accident with a lead vehicle or obstacle; avoidance via simple swerve is where the vehicle swerves into the shoulder or into a clear, adjacent lane; avoidance via signaling is where the vehicle sends a warning signal to a following vehicle. Avoidance via signaling may use rapidly flashing brake lights to gain the attention of the rear vehicle, or may employ communications as will be discussed later.



**"Figure 6. Longitudinal Motion Handling"**

Finally, full tactical driving is introduced. Tactical driving is the ultimate form of full automation within an individual vehicle. At this stage in the deployment process, the vehicle not only tracks and reacts to other vehicles, but also proactively plans out series of maneuvers which are executed to achieve a goal or goals. For example, if the vehicle (or the driver) desires to increase speed and the vehicle is "boxed in," the tactical capability of the vehicle will enable it to plan a way out of the box in order to achieve its goal with a combination of speed changes (including perhaps temporarily slowing down) and lane changes

"Figure 7. Automated Highway System (Radar System)"

### 3.1.3. Obstacle Handling

Obstacle avoidance capabilities reduce or eliminate safety hazards caused by obstacles on the automated highway roadway. This includes rocks, vegetation, dropped vehicle parts, disabled vehicles, and animals such as deer.

One way to reduce the need for obstacle avoidance is to implement obstacle exclusion. To a limited degree this is already deployed with fencing and highway department maintenance of the interstate highway system. Obstacle exclusion can significantly reduce the frequency of obstacles on the roadway, but it seems implausible that any exclusion method can be 100% effective. Thus, more sophisticated forms of obstacle handling will be needed in most foreseeable end-state.

### 3.1.3.1. Baseline Reference Model: Discussion

Figure 3 presents several important items. First, it delineates the evolution of functions within an automated vehicle system, beginning with warning functions and evolving into full vehicle control. The functional dependencies, denoted by solid arrows, identify the critical linkages between functions and clearly define which systems must be mature in order for further capability to be technically feasible.

A major finding in the process of identifying these linkages is the importance of vehicle motion prediction. This capability is critical to the successful implementation of all higher-order full automation functions including lateral, longitudinal, and obstacle handling tasks. It has the added distinction of providing recursive benefits to several already-deployed systems, notable in that no other function does this.

The criticality of this link has not been previously appreciated in the development of AHS subsystems, with efforts generally concentrated in the development of sensors and actuators that manage the lower-level automation functions. This reference model serves to identify and highlight this function's importance.

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Figure 8. Automated Highway System (Los Angeles)"

### 3.2. Communications Reference Model

Figure 9 identifies changes to the functional evolution depicted in Figure 3 when inter-vehicle communication links are introduced. Perhaps the most striking thing about Figure 9 is that there are only two additional functions introduced; indicating that communications are not a necessary element to achieve fully automated tactical driving capabilities.

On the other hand, there are many functions highlighted to indicate that they may significantly benefit from reliable inter-vehicle communications. First, consider those existing functions from Figure 3 that benefit from communications being introduced.

Numerous functions gain from having "pre-maneuver announcement information," which provides greater insight into the future motion of surrounding vehicles, and "inter-vehicle negotiations," which allow vehicles to gain assurances from surrounding vehicles. These existing functions are highlighted in Figure 9, and each of these will be discussed in turn.

Consider a simple lane-changing maneuver. With the addition of communications, a vehicle may "negotiate" with surrounding vehicles to gain assurances that the gap it senses will remain available throughout the maneuver. This may allow simple lane changing to occur in a heavy traffic situation where two adjacent lanes are moving at about the same speed, a significant increase in capability over lane changing in the absence of surrounding vehicles. Even in the case where vehicle-to-vehicle negotiations are not employed, knowing that a local vehicle is moving into a gap near to your vehicle provides additional information about the ever-changing traffic scene, and enables a vehicle to begin readjusting its headway in anticipation of the new situation. adjacent lanes is moving at significantly different speeds, communications enhance maneuver safety by providing intent information before the maneuver can be sensed, and are particularly useful when a maneuver may not be anticipated by the vehicle motion prediction models. So too, merging benefits from knowing a vehicle's exact intention, as opposed to presuming intention. Vehicles that communicate can send assurances that a gap will be maintained, or even created, so that other vehicles can merge into the mainline traffic stream.

A number of longitudinal motion functions also benefit from the introduction of communications. If following vehicles can respond based on the knowledge that a lead vehicle is about to respond to an incident, safety margins are increased over the situation where the vehicle must first sense the incident before responding to it. Avoidance via hard braking, avoidance via lane change, and avoidance via shoulder swerve can improve system safety by announcing maneuvers before executing them, providing a small but possibly significant amount of additional time for the surrounding vehicles to proactively respond.

"Figure 9. Baseline Autonomous Reference Model with Inter-vehicle Communication"

### 3.2.1. Communication Reference Model: Discussion

As shown in Figure 9, the addition of inter-vehicle communications enhances a number of core, in-vehicle functions and enables several new functions. These enhancements and additions, over time, will provide increasingly greater system-wide effects as more vehicles acquire communications capabilities and are able to share information. Two factors influence this reality: the evolutionary nature of these technology-based systems, and the long life span of automobiles. In that a mixture of automation and communication capabilities will be found on any given roadway due to a mixed-aged vehicle fleet, all vehicles must be built to handle all other vehicle types and ages. This is why none of the dependency arrows in Figure 9 change from those presented in Figure 3. The addition of vehicle-to-vehicle communications enables refined estimations of the upcoming traffic situation, however the expected presence of non-communicating vehicles in traffic precludes using communication to alleviate the core in-vehicle requirements.

In addition to the effects and requirements of an evolutionary deployment scheme, there is an additional and important caution about considering an AHS that relies upon communications. The obvious communications medium is radio, but radio has a number of potential reliability problems including correct and timely frequency allocation among multiple proximate vehicles; interference from other sources such as commercial radio transmitters, illegally boosted citizen band radio transmitters, military transmitters or malicious jamming; and interference from natural sources such as lightning strikes. Because of these issues it would not be prudent to rely upon radio communications in a safety-critical role unless reliability is demonstrated across a wide range of environmental conditions or a cost-effective alternative to radio communications can be found. Instead, communications should be treated as information to optimize performance of an AHS, not as a part of safety-critical control loops.

Even if inter-vehicle communications are deemed to be not wide-spread or reliable enough for safety critical functions, the use of communications when available has the potential to increase both individual and global system safety by providing an additional source of detailed information.

### 3.3. Infrastructure Assistance Reference Model

Figure 3 identifies how infrastructure-based capabilities might affect the vehicle evolution. Five new functional boxes are added, and four existing functional boxes from Figure 9 are highlighted to indicate that they either benefit from infrastructure support or could be used in a roadside-based application.

The four existing functions which can benefit by or be adapted for use in the infrastructure are merging, vehicle motion prediction, obstacle detection and relevance determination, and shared obstacle information.

The merging function may benefit from having infrastructure sensors providing gap information, especially on blind merges where the vehicle's own sensors may be limited. Although current highway designs avoid blind merges, many older highways have extremely difficult merge points that are the cause of both congestion and safety problems. Infrastructure-based merge assistance will require infrastructure-based vehicle motion prediction capability in order to provide appropriate gap information to equipped vehicles. This will not obviate the need for vehicle-based vehicle motion prediction, but will use the developed capability in an additional capacity.

"Figure 10. Baseline Autonomous Reference Model with Infrastructure Support"

### 3.3.1. Infrastructure Support Reference Model: Discussion

The introduction of infrastructure support provides a number of system-wide benefits that cannot be achieved with in-vehicle intelligence alone. Most notably flow and route optimization can only be handled with coordination between vehicles and the infrastructure.

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Additionally, merging, obstacle detection, and the sharing of obstacle information can be improved with the addition of infrastructure-based systems.

Notice that the introduction of infrastructure-based systems changes the dependency arrows into the merging function. Merging becomes a beneficiary to lane changing in traffic without being dependent upon it for implementation; the arrow between the two functions is changed to a dashed arrow to reflect this. A new dependency arrow is drawn from vehicle motion prediction, as an infrastructure-based system, to the merging function. In that automated merging may actually become available sooner with infrastructure support than would have been possible with vehicle-based systems alone, this function is moved leftward on Figure 3 relative to Figures 1 and 2.

**"Figure 11. Automated Highway System Using Sensor"**

## IV. OBJECTIVES

Automated highway system's ambitious goals can be achieved by:

Developing advanced concepts for advanced road vehicles for passengers and goods. Most of the earlier projects addressed isolated aspects of the mobility problems of cities, whereas automated highway system focuses on the overall urban transportation problem

Introducing new tools for managing urban transport. automated highway system will develop tools that can help cities to cross the thresholds that are preventing them from introducing innovative systems. For instance, the absence of certification procedures and the lack of suitable business models will be addressed.

Taking away barriers that are in the way of large-scale introduction of automated systems. Some of these barriers are of a technological nature, some are of a legal or administrative nature: for example, the legal requirement for vehicles using public roads where the driver is responsible for the vehicle at all times, which effectively prohibits driverless vehicles from using public roads.

Validating and demonstrating the concepts, methods and tools developed in automated highway system in European cities. In a number of other cities, studies will be carried out to show that an automated transport system is not only feasible, but will also contribute to a sustainable solution for the city's mobility problems, now and in the future.

To survey and document automated highway system with pedestrian safety systems on roads. These systems include crossing control arms, video cameras, radar and acoustic detection systems, **skirts, and collision avoidance systems.**

## V. ADVANTAGES

### 5.1. Help Reduce Pedestrian Accidents: Traffic Signals Place Priority On Crossing Pedestrians

In principle, when traffic conditions are lighter in the daytime, the pedestrian signal remains on green while the driver signal is maintained on red. When a vehicle approaches and stops at the light, the vehicle-system communicates with the traffic light beacon, which then allows the signal to switch to green. This system emphasizes the safety of the pedestrians by ensuring the pedestrian has the right-of-way each time.

When a driver slows down accordingly on approaching an intersection, the system again synchronizes the timing of the green signal with the approaching vehicle to minimize the need for repeated stops and acceleration, thus improving on-the-road fuel consumption under city-driving conditions. The test program will also include a virtual school zone*2, which will appear as a warning alert to speeding vehicles on its on-board navigation display.

### 5.2. Help Reduce Collisions Due To Traffic-Signal Oversights: Have Traffic-Signal Alerts On-Board Vehicles

The traffic-signal alert system automatically appears on the navigation display as a vehicle enters within a specified distance to an approaching traffic light. This alert system is already being tested on public roads under the ITS project in Kanagawa. To help minimize accidents due to traffic-signal oversights,

### 5.3. Reduce Congestion Caused By Red Traffic Signals And Right-Turn Queues

Traffic congestion is often caused by red traffic signals and vehicles queuing to take a right turn from one lane streets. Nissan is developing its ITS system to optimize the timing intervals between changing traffic signals to correspond with real-time traffic volume and flow in order to ease traffic congestion. The advanced system is able to detect and respond to right-turning vehicles, thus reducing the queuing time and improve traffic flow at intersections. Current research is moving forward on methods to synchronize groups of traffic signals to facilitate smooth traffic flow over a wider scope of traffic conditions.

### 5.4. Computing Power, Sensing Capacity, And Wireless Connectivity For Vehicles Rapidly Increase

The reliable intelligent driver assistance systems and safety warning systems is still a long way to go. However, as computing power, sensing capacity, and wireless connectivity for vehicles rapidly increase, the concept of assisted driving and proactive safety warning is speeding towards reality. As technology improves, a vehicle will become just a computer with tires. Driving on roads will be just like surfing the Web: there will be traffic congestion but no injuries or fatalities. Advanced driver assistant systems and new sensing technologies can be highly beneficial, along with large.

## VI. CONCLUSIONS

Transportation systems are an indispensable part of human activities. Estimation shows that an average of 40% of the population spends at least one hour on the road each day. People have become much more dependent on transportation systems in recent years; transportation systems themselves face not only several opportunities but several challenges as well. The competitiveness of a country, its economic strength and productivity heavily depend on the performance of its transportation systems.

Three successively more comprehensive reference models have been presented to depict how an AHS might evolve using incremental introduction of functionality. These models indicate precedence constraints on the introduction of capabilities and depict how the introduction of inter-vehicle communication and infrastructure support can increase the efficacy of an AHS. The models also demonstrate that addition of additional capabilities in most cases does not supplant previously introduced in-vehicle functionality.

The first reference model suggests that full tactical driving capability requires neither inter-vehicle communication nor roadside-to-vehicle communication. However, if robust communication mechanisms can be provided, communications might be used to significantly improve the quality of maneuvering and collision avoidance capabilities. With the exception of merging, adding communication capabilities does not obviate the need for any vehicle based functions when these vehicles are incrementally introduced onto an existing roadway system. The presence of non-AHS-equipped and older-but-equipped vehicles in an incremental deployment scheme necessitates the development of in-vehicle systems that can function effectively without relying on communication. Even though an end-state of full automation is desirable, the reality is that an incremental deployment will be necessary. As shown by the reference models, there appear to be a number of obtainable safety and efficiency benefits at intermediate deployment points utilizing partial automation and in some cases no automation. Using these models as a roadmap may help plan evolutionary approaches to creating an AHS that satisfy both technical constraints and a need to provide value before fully automated operation is achieved.

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