Vehicle–Highway Automation
Directions, Challenges, and Contributing Factors

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The implementation of vehicle–highway automation early in the 21st century will provide an enhanced level of surface transportation accessibility and mobility. Vehicle–highway automation will take many forms and collectively these advanced control technologies will be the most important performance upgrade of the nation's surface transportation system since the advent of the interstate highway system. Benefits will result through improvements in safety, spurred economic development, reduced traffic congestion, and extended mobility for many, especially the elderly and disabled.

SAFETY AND PERFORMANCE IMPROVEMENTS

Vehicle–highway automation technologies and systems can be described in four categories:

- Warning systems that sense and then advise drivers of potential hazards;
- Control assistance systems that augment the driver's ability to control the vehicle;
- Control override systems that intervene in some aspect of the control of the vehicle during unsafe conditions; and
- Automated control systems that control all motions of the vehicle.

These systems may be implemented by technology that is entirely contained within the vehicle (i.e., autonomously) or by combinations of in-vehicle and infrastructure technologies (i.e., cooperatively). The potential benefits to society and individuals are manifold in terms of productivity, mobility, and safety, and thus, overall trip quality. In terms of *productivity*, increases in throughput of perhaps a factor of three would result in increases in effective highway capacity that would, in turn, alleviate the need to build new lanes or seek other costly means of accommodating the predicted significant continuing increases in travel demand. Users would reap the benefits of substantially reduced and more predictable travel times.

In terms of *mobility*, more predictable and generally reduced trip times would allow users expanded options in their personal and business endeavors. Impaired and elderly drivers may be able to travel safely, and with less anxiety, by automobile on high-demand urban freeway-type facilities. Transit systems, likely early users of vehicle–highway automation, could offer improved quality of service less vulnerable to traffic congestion.

In terms of *safety*, vehicle–highway automation will use advanced sensing and computing technologies to provide improvements over human performance. These include full attentiveness, consistent responses, and lightning-quick reaction times. Applied in carefully selected operating environments and with appropriate fault-handling features, vehicle–highway automation will result in significant decreases in the frequency and severity of highway crashes.

Automation has the potential to generate fundamental changes in transportation. This paper describes some probable directions, recognizing that the actual future depends mostly on how transportation automation opportunities evolve and integrate with the future needs of individuals and society.

DEVELOPMENT AND IMPLEMENTATION: SOCIETY’S CHOICES

The way society resolves its needs and deals with its limitations will shape the future of the nation's vehicle–highway system. Safety, availability, reliability, environmental considerations, land use, and energy costs, and each of their interacting influences on private, business, and government activities, will affect vehicle–highway demand, actual use, and operations. Thus, how we incorporate automation into the vehicle–highway system will be subject to society's choices on each of a broad set of quality of life parameters.

Some argue that the current infrastructure is so large that this investment dominates the reality of the future of transportation, and small changes at the margin are all we can expect. Certainly, the existing highway infrastructure in some ways constrains the design options for various vehicle–highway automation concepts. However, we believe that, because of its many inherent advantages, automation will contribute significantly to the surface transportation systems in the new millennium.

The actual future rate of implementation of vehicle–highway automation will primarily reflect market forces such as the services that suppliers and consumers think people need tempered by their capacity to accept and afford them. The policies and effectiveness of local and regional transportation service providers to deliver adequate highway capacity and transit services will have a substantial bearing on rates of implementation in both rural and metropolitan areas. Additional influences will include vehicle marketing as it reflects perceived trends, national safety policies such as a reduced tolerance for behavior that leads to crashes, and national resource allocation policies.

Probable Directions

Since the World’s Fair of 1939, the public image of “advanced” automobiles has been frequently updated and expanded in the media, advertising, and marketing and trade show world of automobile image making. Nearly everyone has an image of the car of the future. How much of the image becomes reality depends on the two issues of public demand and the availability and cost of new technologies and systems.

New technologies and capabilities are in position to substantially alter the driving process. Some examples are the burgeoning intelligent transportation systems industry with expectations for the “auto PC,” new services to assist drivers improve their safety and effectiveness, new businesses that provide greater mobility, cooperation in global automobile manufacturing, and new infrastructure designs and materials.

Especially important are the increasingly closer working relationships among industry and government interests to develop and implement vehicle–highway automation technologies and systems. This approach can be particularly fruitful if it facilitates the development of truly cooperative vehicle–highway technologies that bridge the traditional divide between the vehicle and infrastructure sectors.

Various scenarios can be visualized for the development and application of vehicle–highway automation over the next several decades.

Typical Highway Situations

Most vehicle–highway interests see the beginning applications of automation occurring in control assistance systems for passenger and commercial vehicles operating in typical highway situations. These systems sense specific dangerous or deviant driving situations and provide some form of feedback to the driver. In early systems this feedback may simply be an auditory warning; in more advanced versions, this feedback may take the additional form of partial vehicle control assistance. Examples include vehicle-based collision warning systems that are now available and provide an auditory and visual warning to the driver. In the near future, these systems may actually apply the brakes in certain defined situations.

Another area of interest is systems that warn of or provide control assistance in imminent run-off-the-road situations. Again, driver assistance may include auditory and visual warnings as well as possible corrective forces applied to the steering system. Depending on the design, these corrective forces may be relatively light and easily overridden by the driver or in-lane guidance systems; they may be sufficient to maintain the vehicle in the traveled lane.

Research and development are also focusing on vehicle- and highway-based systems that will provide intersection crash avoidance in various driving situations.

Specialty Vehicle Operations

The two primary areas in which to expect specialty vehicle development are maintenance and emergency operations. Routine maintenance is the mainstay of maintenance forces and the major challenges are improving safety and reducing operational costs. In the safety arena, accident data indicate points at which maintenance employees are most at risk and where vehicle automation can provide additional operational safety.

The normal method of protecting highway construction and maintenance workers is the establishment of work zones with the appropriate signing, marking, and barriers. In moving maintenance situations, automated systems provide the opportunity to automate the trailing “guard” vehicle.

Two other possible safety systems offer great promise in the coming years: maintenance vehicle guidance in bad weather and roadside obstacle detection. Vehicle guidance systems received a significant boost with the development of the technologies produced for the National Automated Highway Systems Consortium's Demo '97 exhibit in San Diego. Several of the guidance concepts are being tested to determine which ones will provide the most durable and reliable guidance for snowplows operating in heavy whiteout conditions (probably the most extreme service requirement).

Avalanche removal offers several safety hazards to operators that can be mitigated by automation. Plows, loaders, and snow cats are used to clear slides that cover roadways. Even when this equipment is available, it is often not used if there is a perceived risk of another slide occurring during the clearance. In Colorado and other states, shelling of the slope above the avalanche path is a common way of ensuring stability. This creates another problem of unexploded ordnance in the avalanche debris field that could be detonated by clearance equipment. Automation of snow removal equipment in these circumstances would use a remote-controlled vehicle with an operator situated at a somewhat remote, but safe, distance.

Transit Vehicle Operations

Automation will provide the potential for transit services to expand from the traditional surface street operations to provide more transportation options. A notable example could be bus rapid transit (BRT) operated on dedicated rights-of-way along congested corridors to connect employment, business, and residential concentrations. BRT vehicles will be fully automated within the corridor using lateral guidance and longitudinal control. Automated docking together with alternative bus designs (e.g., low floor and large doors) will offer fast and convenient passenger loading and unloading at the platforms, thus reducing stop times. At peak hours on congested corridors, buses can be operated as groups with smaller headways. When operated outside of the corridor, buses can be either manually controlled or operated using partial automation such as electronic guidance. BRT has the advantages of rail transit for reliable and high-frequency service and the flexibility to operate outside the corridor and in various express patterns, potentially for door-to-door service. BRT features could attract significant numbers of commuters from single-occupancy vehicles and thus contribute to the reduction of traffic congestion on the corridor. The BRT capabilities can be extended from full-size buses to smaller buses and other high-occupancy vehicles (HOVs), including carpools and vanpools. The specially equipped HOVs would be able to make more efficient and safe use of their dedicated highway lanes, providing an attractive opportunity for progressively staged deployment of vehicle–highway automation technology.

Vehicle–highway automation technologies may be implemented on transit vehicles earlier than on other vehicle platforms because of the limited roadway infrastructure needed for the fixed-route service and the advantage of having vehicle and infrastructure operations under common management decision-making. In addition to the BRT application, vehicle–highway automation technologies could be used individually for bus platform precision docking and specialized daily bus maintenance activities.

Commercial Vehicle Operations

Some commercial trucks are already making use of the earliest elements of vehicle–highway automation in the form of forward and side collision warning systems. These will soon be joined by lane-departure warning and adaptive cruise control systems, which are intended to improve driving safety, comfort, and convenience. Technological innovations such as these can be implemented earlier on commercial trucks than on private passenger cars because the deployment decisions are motivated directly by economic considerations (benefits exceeding costs), the costs of the systems are small fractions of the cost of the vehicle, the drivers are professionals with special training, and the vehicles are typically serviced and maintained professionally as well. In the future, commercial trucking could represent fertile territory for the development of the more advanced automated driving features for many of the same reasons. This has been recognized in major truck automation development projects in Japan, Germany, and the Netherlands. In some U.S. locations with particularly heavy truck traffic, consideration is already being given to the development of special truck-only lanes to segregate trucks from light-duty vehicles. Some of these locations could be promising sites for automated truck lanes, particularly in corridors where much of the truck traffic is represented by fleet vehicles that spend most of their time within the same corridor. The potential fuel savings from close-formation automated platoon driving of trucks is already a strong incentive to encourage the development of automation for trucks. The economics of truck automation could become particularly attractive if the reduced stress and driving responsibilities justified the relaxation of driver duty-time limits.

Fully Automated Operations in Controlled-Access Lanes

The concept of fully automated highway systems has the potential of offering dramatically increased throughput and safety without requiring a significant amount of right-of-way acquisition, depending on specific implementation concepts and sites. Research results to date indicate that integration of advanced sensor, communication, computer, and control technologies in vehicles and the roadway infrastructure can safely reduce the average spacing among vehicles at highway speeds. These technological capabilities provide the basis for the most dramatic advance in road transportation since the limited-access interstate-class highway.

The opportunities offered by full automation of highway travel are potentially dramatic:

- Enhanced mobility for aging and disabled drivers who are currently intimidated by highway driving;
- Reduction of the stress and tedium of driving for both commuters and long-distance drivers;
- Elimination of adverse human driving behaviors in the automated lanes;
- Significant reductions in urban highway congestion;
- Significant reductions in emissions and fuel consumption per vehicle miles traveled by means of aerodynamic drag reductions from close-formation automated driving; and
- Generally reduced impedance to highway travel.

Challenges
The advantages of automation will have political and institutional costs. For example, the process of deployment of vehicle–highway automation projects will raise several crucial issues. The dilemma requires coordinated development and implementation of both vehicle and roadway infrastructure systems. A large-scale deployment would require successful resolution of challenging institutional issues such as

- Can the vehicle and infrastructure developments be coordinated and synchronized?
- Can the investment and financing be obtained?
- What are the net environmental impacts?
- How are land use policies affected?
- How are liability, insurance, and risk factors partitioned?

Although an automated highway system may not require a significant amount of right-of-way acquisition, it may still require considerable modification to current highways. This could include the addition of segregated lanes within space-constrained rights of way, the increased complexity of highway-highway interchanges that require continuous segregation of the automated traffic from the conventional traffic, and the adaptation of access and egress points to accommodate increased traffic volumes.

FUTURE RESEARCH AND DEVELOPMENT
Vehicle–highway automation is a sufficiently new field that many important research and development issues remain to be addressed. Some of the most challenging research issues involve the need to understand human interactions with automation technologies. Surprisingly little of this is understood today, and much research is still needed on issues such as

- Driver attentiveness during partially and fully automated driving;
- Making successful transitions among manual, partially automated, and fully automated driving (in both directions);
- Potential changes in driving behavior when warning, control assistance, or automated systems are available (risk compensation, decrements in driving skills, etc.); and
- Acceptability and desirability to drivers of different levels of warning, control assistance, and automation.

Many of the vehicle–highway automation systems are intended to improve traffic safety, but the data and tools needed to determine their effects on safety are not yet available. Considerable research attention needs to be devoted to increasing understanding of traffic safety problems and the ways in which the automation systems may influence them:

- Precise identification of hazards in the driving environment, including issues such as the types of obstacles that could be encountered on the road;

- Quantitative description of the driving environment in which the new systems must be able to operate; and
- Comprehensive baseline data to define the causes of the crashes and near-misses that occur today and the extent to which these could be mitigated (or possibly exacerbated) by use of automation technologies.

The largest effects on the transportation system will be produced by the most advanced of the vehicle–highway automation systems, the truly automated highway system. Although it is clear that this provides the opportunity for a significant increase in highway capacity, considerable research is still needed to develop the underlying theory, as well as the models, to define the full range of the effects it can have on issues such as

- Changing travel patterns, by time of day as well as origins and destinations;
- Potential for stimulating latent and induced travel demand, with possible net environmental consequences;
- Interactions of entering and exiting traffic with the rest of the transportation network;
- Changes in public perceptions of the nature of travel itself; and
- Net safety of travel, in both automated and manual modes of operation.

To realize the potential for great benefits, many remaining research issues must be studied intensively in the next millennium.

VISION FOR THE FUTURE

Automation is expected to thrive early in the 21st century in all aspects of private vehicle, commercial, transit, and specialized vehicle operations. However, the rate of progress and the eventual characteristics of operational systems will be significantly affected by so many factors that it is difficult to predict with any certainty which forms will be deployed and at what rate. It is clear, however, that vehicle–highway automation is the next significant stage in the development of the vehicle–highway system, and it is expected to

- Assist the driver control the vehicle;
- Increase user safety; and
- Increase the vehicle–highway productivity and performance.

But how will this technology mature? It may come through specific and localized vehicle–highway automation concepts. Examples abound: in transit (e.g., BRT, with its dedicated highway lanes), in commercial vehicles through the economic benefits potentially realized by truck convoys (e.g., the European CHAUFFER-electronic tow-bar project), or with specialized high-throughput corridors (e.g., a dedicated adaptive cruise control-only “pipeline” on an HOV facility for comfortable, high-throughput transportation from an outlying suburb to a central business district or between two urban centers).

A limited subset of vehicle–highway automation services could also come about through the development of improved vehicle-based systems. In this manner, convenience and perhaps safety benefits would drive the piecemeal usage of some vehicle–highway automation capabilities within mixed traffic. This approach would arise from natural market forces that would create a demand, assuming that a favorable regulatory environment and appropriate levels of safety can be guaranteed. Because of the mixed traffic aspect of this system, increased transportation efficiency is not likely to be a significant benefit; rather, convenience and safety benefits would be the market drivers. The beneficiaries of such a system would likely be travelers in uncongested suburbs or in rural areas.

Regardless of the final path of development and deployment, vehicle–highway automation is one of the most significant technologies that will become common in the 21st century and will shape the future of the surface transportation system.