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# Intelligent vehicle applications worldwide

Richard Bishop

Intelligent vehicles is an application in which the words “intelligent autonomous systems” represent not only an important research topic but also a strategic solution to the mobility problems of the coming years. Vehicles that can move autonomously and navigate in everyday traffic, in highway, urban, and unstructured scenarios, will become a reality in the next decades. Besides the obvious advantages of increasing road safety and improving the quality and efficiency of people and goods mobility, the integration of intelligent features and autonomous functionalities on vehicles will lead to major economic benefits from reduced fuel consumption, efficient exploitation of the road network, and reduced personnel. Furthermore, not only the automotive field (public transportation, trucks, and automobiles) is interested in these new technologies, but also other sectors, each with its own target (industrial vehicles, military systems, mission-critical systems, and unmanned rescue robots).

In this second issue of the ITS department—written in cooperation with the IEEE Intelligent Transportation Systems Council—Richard Bishop surveys the major intelligent vehicles projects and activities worldwide, covering not only automotive applications but also special vehicles.

You can download the ITS Council’s newsletter from the Council’s official home page at [www.ieee.org/itsc](http://www.ieee.org/itsc) (which also contains information and calls for papers for upcoming ITS conferences) or from the Italian mirror site at [www.ce.unipr.it/itsc](http://www.ce.unipr.it/itsc).

For further information and for suggestions, contact me at [broggi@ce.unipr.it](mailto:broggi@ce.unipr.it); [www.ce.unipr.it/broggi](http://www.ce.unipr.it/broggi).

—Alberto Broggi

**T**he field of intelligent vehicles is rapidly growing worldwide, both in the diversity of applications and in increasing interest from the automobile, truck, public transportation, industrial, and military sectors. IV systems offer the potential to significantly

enhance safety and operational efficiency. As one component of intelligent transportation systems, IV systems use sensing and intelligent algorithms to understand the vehicle’s immediate environment, either assisting the driver or fully controlling the vehicle. Following the success of information-oriented systems, IV systems will likely be the “next wave” for ITS, functioning at the control layer to enable the driver–vehicle “subsystem” to operate more effectively. This column provides a broad overview of applications and selected activities in this field.

## IV application areas

We can readily segment IV application areas into systems that

- advise or warn the driver (*collision warning*),
- partially control the vehicle, either for steady-state *driver assistance* or as an emergency intervention to avoid a collision (*collision avoidance*), or
- fully control the vehicle (*vehicle automation*).

Collision-warning systems include functions such as forward-collision warning, blind-spot warning, lane-departure warning, lane-change or merge warning, intersection-collision warning, pedestrian detection and warning, backup warning, rear-impact warning, and rollover warning for heavy vehicles. A special category of collision warning is driver monitoring, to detect and warn of drowsiness or other impairments that prevent the driver from safely operating the vehicle.

If the driver does not adequately respond to warnings, collision-avoidance systems might take control of the steering, brakes, or throttle to maneuver the vehicle back to a safe state. Driver-assistance systems include functions such as adaptive cruise control, lane keeping, precision docking (which I’ll describe later), and precise maneuvering.

Vehicle-automation systems include low-speed automation, autonomous driving, and close-headway platooning (which provides increased roadway throughput), and electronic vehicle guidance in segregated areas such as busways and freight terminals. These systems can be *autonomous*, with all instrumentation and intelligence on the vehicle, or *cooperative*, where assistance comes from the roadway, other vehicles, or both. Roadway assistance typically takes the form of passive reference markers in the infrastructure. Vehicle–vehicle cooperation lets vehicles operate in closer proximity for increased efficiency, usually by transmitting key vehicle parameters and intentions to following vehicles. The general philosophy is that autonomous systems will work on all roadways in all situations at a useful performance level and take advantage of cooperative elements, as available, to augment and enhance system performance.

## Automobiles

Passenger car applications could provide a substantial benefit by alleviating the hun-

dreds of thousands of deaths and injuries that occur annually worldwide from highway accidents. However, because of the need to minimize false alarms and maximize reliability for this consumer market, the introduction of automobile systems is proceeding slowly, although steadily.

**Collision warning.** The CW systems listed earlier have been extensively prototyped and tested. Night vision and backup-warning systems are now available on some automobiles, and Mitsubishi and Nissan have announced the near-term availability of CW packages. Forward-collision warning and lane-departure warning should become available in the next few years. The Japanese Smartway concept will implement user services such as lane keeping, intersection collision avoidance, pedestrian avoidance, and headway keeping. A model-deployment project should be operational by 2003, with nationwide implementation in 2015. In late 2000, the Japanese government and the Advanced Cruise-Assist Highway System Research Association will sponsor Smart Cruise 21, a major proving test and public demonstration.

European Commission funding is also supporting research in longitudinal and lateral collision warning. The US Intelligent Vehicle Initiative (IVI) program is establishing a partnership with key automotive manufacturers to perform precompetitive research in human factors (driver workload), high-accuracy digital map databases, and the development of metrics and testing methodologies for collision-warning and collision-avoidance products.

**Driver assistance and collision avoidance.** The high-profile driver-assistance product is adaptive cruise control, available in Europe and Japan and soon to be introduced in the US. ACC senses slower vehicles ahead and adjusts speed to establish a safe following distance, resuming the desired speed when the road ahead is clear. Current ACC systems are geared for highway speeds; the next-generation systems (now in testing) will also support stop-and-go congested conditions. In 1999, Mitsubishi introduced its new Driver Support System in Japan, which supplements ACC with lane-departure warning and side and rear monitoring through machine vision.

Honda, Nissan, and Toyota have developed several safety subsystems in the joint

Advanced Safety Vehicle project, including lane positioning, headway control, automatic braking, obstacle warning, drowsiness warning, and nighttime pedestrian warning. Publicly funded research in Europe is focusing on driver monitoring, road-condition sensing, vision enhancement, heading control (intelligent steering control to optimize a vehicle's trajectory), and sensor fusion. The US Department of Transportation (DOT) has begun a five-year, \$35-million project with General Motors to develop and test preproduction rear-end collision-avoidance systems.

**Automated operation.** Fully automated vehicle operation offers safe travel, more efficient traffic flows, and driver convenience. This capability has been prototyped and demonstrated extensively during the

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'90s, establishing technical feasibility. Current research focuses on refining system approaches. Fully functional automated cars, developed by the University of Korea, the Mechanical Engineering Laboratory in Japan, the University of Pavia (Italy), Ohio State University, and the University of California, among others, are being tested and refined.

In the near term, low-speed automation should be very popular. LSA would be engaged in slow, congested traffic, so that the driver can relax instead of controlling the vehicle under these tedious conditions. When the congestion clears and speeds increase, the driver would resume control. This capability is being developed in both Asia and Europe. It was planned for demonstration in Korea in late 1999 on the KAV vehicle, and the European Commission is initiating an LSA project under their Fifth Framework research program in 2000. Japanese auto manufacturers are also developing prototype systems; for instance, Nissan has defined the "2D-ACC" concept on

their 2001-c testbed vehicle, in which an LSA system combines stop-and-go ACC and lane keeping with automated steering control.

### **Heavy trucks**

The heavy truck market represents an ideal industry for early implementation of IV systems, because collision costs are a major drain on profit. Current prices for IV systems, although high by consumer standards, are a small fraction of the price of a full-size truck tractor, and collision-reduction benefits can be measured to support business investment decisions. Furthermore, truck drivers are professionals; they can be trained to operate new systems and can provide feedback for product refinement.

**Collision warning.** Over 10,000 radar-based CW systems are now operating on heavy trucks in the US; similar units should become available soon in Europe and Asia. Lane-departure warning systems became available in 1999, based on machine vision techniques that interpret the road scene to detect the travel lane's edges. DaimlerChrysler has announced that this feature will be available on trucks sold in Europe and the US in 2000. The US IVI program has initiated three operational tests focusing on collision countermeasures for heavy trucks: Freightliner Corporation is testing a Rollover Stability Advisor device; Mack Trucks is testing infrastructure-assisted hazard warning and automatic collision notification; and Volvo Trucks is evaluating forward-collision warning, blind-spot warning, ACC, and electronic braking systems.

Because fatigue plays a major role in truck accidents, the US DOT has a highly active program developing drowsy-driver countermeasures for the trucking industry. Research has focused on understanding fatigue factors in driving, defining measurable physiological parameters, developing in-vehicle systems that can unobtrusively monitor the driver, and developing warnings and techniques to help the driver regain alertness. Researchers are testing a variety of system approaches.

**Driver assistance and collision avoidance.** Collision-avoidance systems will follow successful experience with the CW systems described previously. Forward-collision-warning alerts can be enhanced with brake

activation. The ability to provide precise, and differing, brake forces at individual wheels opens the way to electronic stability control, which has great potential to reduce rollovers. ESC should become available in Europe by 2001, with slower implementation in the US. ACC became available for US trucks in 1999, and all US truck manufacturers are integrating this capability into their standard product line. In evaluations of ACC, truckers report that it substantially reduces fatigue and saves fuel.

**Automated operation.** DaimlerChrysler, Renault VI, and Iveco are participating in the Chauffeur project to develop an electronic tow-bar capability to enable close-headway convoying of heavy trucks, with following trucks fully automated. (For links to more information on Chauffeur and other IV research, see the sidebar.) Chauffeur researchers successfully demonstrated initial capability of a two-truck convoy in 1999, with the driver in the following truck turning over control to the automated system. The University of Minnesota has developed the SafeTruck concept, which provides for a virtual bumper around the truck based on sensing data. The system gives alerts as needed; if the driver loses control, the system intervenes, drives the vehicle to the shoulder, and stops it.

### **Public transportation**

Buses also represent an opportunity for early deployment, because the operating entity owns the fleets and sometimes the roadways themselves. The US IVI program is investing in the development of bus-collision countermeasures, and precision maneuvering of buses using electronic guidance offers substantial advantages over existing operations.

**Collision warning.** Currently, research on CW for buses is occurring only in the US, under the IVI program. Although bus accidents do not result in large numbers of severe injuries or fatalities, the economic costs of minor accidents are substantial (estimated at \$800 million nationally). The Federal Transit Administration is working with local transit agencies to develop performance specifications for lane-change, forward, and rear-impact collision warning.

**Driver assistance and collision avoidance.** As with trucks, collision-avoidance

systems for buses will be a natural follow-on to successful implementation of CW systems. A key driver-assistance feature is precision docking, which lets a bus consistently pull up to a bus stop with a minimal gap from the edge of the bus door to the curb. This seemingly innocuous capability optimizes the flow of passengers and prevents mishaps. Precise docking has been demonstrated using both machine vision and magnetic referencing. Transit agencies worldwide are actively interested in this application, with initial implementations expected in 2000.

**Automated operation.** Electronic guidance of buses offers people-carrying capacity approaching that of a light-rail system, without the capital costs required with rail. Because of space restrictions in urban areas, bus-only lanes are often very narrow. Electronic guidance lets a bus precisely

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track within its designated lane at full speed. Electronically guided bus systems are now being implemented in the Netherlands, France, England, and Japan. In the US, several transit agencies are planning or considering electronic-guidance systems, with support from the federal Bus Rapid Transit program. Caltrans (the State of California DOT) is actively developing automated buses, with a demonstration planned for 2002. Guided bus systems are also under consideration in Sao Paulo, Brazil, and other South American cities.

Rubber-tired people movers are another area of research and deployment. One such example is the unmanned ParcShuttle at Amsterdam's Schiphol Airport. ParcShuttle implements a "horizontal elevator" concept, using free-ranging-on-grid (FROG) technology to pick up people at remote parking sites and take them to their desired terminals.

### **Special vehicles**

Current research in this area focuses on snow removal for highway maintenance, automation of repetitive vehicle movements in industrial complexes, and autonomous vehicles for military operations.

**Snow removal.** California and Minnesota are testing systems that provide lane-edge indications to snowplow drivers attempting to clear roads in low or zero-visibility conditions resulting from high winds or blizzards. To provide lane tracking, the systems either apply magnetic referencing to the highway, indicating each lane's position, or use highly accurate digital maps and precise GPS positioning on board the snowplow. In each case, the driver remains in control of the steering, using a display indicating the lane edge to accurately guide the snowplow. The IVI program has awarded an operational test to the Minnesota DOT to provide expanded testing of these techniques.

In addition, Caltrans plans to develop an unmanned snowblower that will operate in dangerous mountain passes.

**Industrial automation.** At seaports, shuttling of transport containers is typically done by "yard tractors," which take on containers at shipside and transport them several hundred meters away to a storage area. The Port of Rotterdam has automated this highly repetitive operation with FROG transponder technology. Other ports worldwide are considering implementing such a system.

Additionally, large industrial complexes might have substantial freight movements between on-site facilities, which are typically served by trucks. In the Combi-Road system, developed in the Netherlands, unmanned tractors operating on a dedicated path carry freight back and forth between such points. The system uses magnetic lateral referencing, along with an array of optical beacons to detect obstacles. Implementation is now under discussion for an industrial site in the southern part of the Netherlands, and the Dutch government is considering this approach for transporting freight out of the Port of Rotterdam and distributing it throughout the country via special lanes constructed alongside the public highways.

**Military operations.** The US Department of

## URLs of interest

- General intelligent-vehicles information: [www.itsa.org/ivi.html](http://www.itsa.org/ivi.html)
- Advanced Cruise-Assist Highway System Research Association: [www.ahsra.or.jp](http://www.ahsra.or.jp)
- Chauffeur: [www.trentel.org/transport/research/Projects/chauffeur.html](http://www.trentel.org/transport/research/Projects/chauffeur.html)
- Demo III: robotics.jpl.nasa.gov/people/arankin/98.auvsi/sld001.html
- Electronic bus guidance: [www.lagardere.fr/us/connaitre\\_le\\_groupe/activites/auto\\_transport.html](http://www.lagardere.fr/us/connaitre_le_groupe/activites/auto_transport.html)
- La Route Automatisée: [www.lara.prd.fr](http://www.lara.prd.fr)
- Minnesota snowplow operations: [www.dot.state.mn.us/guidestar](http://www.dot.state.mn.us/guidestar)

Defense seeks to deploy unmanned vehicles for hazardous military scout missions. Demo III, the current, third-generation program, calls for highly capable vehicles operating cooperatively both on-road and off-road. Requirements for on-road operations create an overlap with ITS, and useful spin-offs to the automobile and truck industries are expected. The vehicles must operate both singly and in convoys on highways at up to 65 kilometers per hour, and off-road at up to 32 kmph. The Demo III sensor suite includes a forward-looking 77-GHz FMCW (Frequency Modulated Continuous Wave) radar, stereo machine vision (separate color, monochrome, and infrared cameras) with gaze control, lidar (laser radar), 2-GHz foliage-penetrating radar, and rear-vision cameras. Initial on-road operations are planned for demonstration in late 2000, with full capability achieved at the program's conclusion in 2001.

Autonomous scout vehicles are also under development in Germany. The Primus program uses substantial machine vision capabilities, with a two-axis platform for gaze control of a color camera. This program has achieved 50 kmph on-road and 10 kmph off-road operations, with lidar sensing for obstacle detection.

**T**he activities I've described here indicate a steady stream of research and deployment over the next several years. The year 2000 will see significant Japanese activity, especially with Smart Cruise 21. ACC for automobiles will gain popularity during this time, as well. Attention might begin to turn to the evaluation results of the US DOT operational testing of heavy trucks around 2001 and to initial implementation of driver assistance and automation for bus transit between 2001 and 2004. California plans to demonstrate fully automated trucks and buses in 2002. Low-speed automation is planned for initial capability in 2003 in Europe and could likely be commercially

available shortly thereafter in Europe or Japan. In the longer term, Japan aims to reduce motor vehicle accidents by 15% by 2010, with their Smartway concept fully implemented in 2015. Korea has targeted 2020 for achievement of vehicle-highway automation. All players see deployment as an evolutionary, incremental process.

A key benefit of bus and special-vehicle deployments is the public's raised awareness of and confidence in these systems, which will stimulate consumer demand and public support for government initiatives and provision of supporting infrastructure. System deployment on heavy trucks will provide substantial real-world testing to help refine systems for the automobile market.

Overall, the question "Should we implement these systems?" appears to have been satisfactorily answered—government transportation officials understand the benefits, demonstrations have established credibility and technical feasibility, and the vehicle industry sees a ready market in its customer base. So, the question now is, "How should we implement the systems?" The supporting technology is fairly mature, and work is focusing on choosing the best mix of technologies and adapting them for the vehicle-highway environment, optimizing the human-machine interface, defining workable deployment paths, and cultivating government-industry cooperation to accelerate deployment. Clearly, the next wave of vehicle innovations is reaching the shore, offering more efficient movement of goods and safer, less stressful driving. ■

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