Every minute, on average, at least one person dies in a crash. If you read this article from start to finish, 30 or more deaths will have occurred across the globe by the time you are done. Auto accidents will also injure at least 10 million people this year, two or three million of them seriously.

All told, the hospital bills, damaged property, and other costs will add up to 1–3 percent of the world's gross domestic product, according to the Paris-based Organization for Economic Cooperation and Development. For the United States alone, the tally will amount to roughly US $200 billion. And, of course, the losses that matter most are not even captured by these statistics, because there's no way to put a dollar value on them.

Keeping Cars

Adaptive cruise control is here, the first step toward systems that can help cars keep their distance on crowded highways

BY WILLIE D. JONES
Assistant Editor

Engineers have been chipping away at these staggering numbers for a long time. Air bags and seat belts save tens of thousands of people a year. Supercomputers now let designers create car frames and bodies that protect the people inside by absorbing as much of the energy of a crash as possible. As a result, the number of fatalities per million miles of vehicle travel has decreased. But the ultimate solution, and the only one that will save far more lives, limbs, and money, is to keep cars from smashing into each other in the first place.

That is exactly what engineers in the United States, Europe, and Japan are trying to do. They are applying advanced microprocessors, radars, high-speed ICs, and signal-processing chips and algorithms in R&D programs that mark an about-face in the automotive industry: from safety systems that kick in after an accident occurs, attempting to minimize injury and damage, to ones that prevent collisions altogether.

The first collision-avoidance features are already on the road, as pricey adaptive cruise control options on a small group of luxury cars. Over the next few years, these systems will grow more capable and more widely available, until they become standard equipment on luxury vehicles. Meanwhile, researchers will be bringing the first cooperative safety systems to market. These will raise active safety technology to the next level, enabling vehicles to communicate and coordinate responses to avoid collisions. Note that to avoid liability claims in the event of collisions between cars equipped with adaptive cruise control systems, manufacturers of these systems and the car companies that use them are careful not to refer to them as safety devices. Instead, they are being marketed as driver aids, mere conveniences made possible by new technologies.

Further in the future, developments by private research groups and publicly funded entities such as the U.S. Department of Transportation's Intelligent Transportation Systems (ITS) Joint Program Office, and Japan's Advanced Cruise-Assist Highway System Research Association, may make driving a completely automated experience. Communication among sensors and processors embedded not only in vehicles but in roads, signs, and guard rails are expected to let cars race along practically bumper to bumper at speeds above 100 km/h while passengers snooze, read, or watch television.

What's that up ahead?

Such scenarios are 20 years away at least. Fortunately, automakers can do a great deal to improve safety with present technology. They have already started equipping high-end vehicles with sensors that detect motion and obstacles, coupled to processors that respond instantly to whatever is detected.

These adaptive cruise control (ACC) systems, which add $1500 to $3000 to the cost of a car, use laser beams or radar to measure the distance from the vehicle they are in to the car ahead and its speed relative to theirs. If a car crosses into the lane ahead, say, and the distance is now less than the preset minimum (typically a 1- or 2-second interval of separation), the system applies the brakes, slowing the car with a maximum deceleration of 3.5 m/s^2 until it is following at the desired distance. If the leading car speeds up or moves out of the lane, the system opens the throttle until the trailing car has returned to the cruise control speed set by the driver.

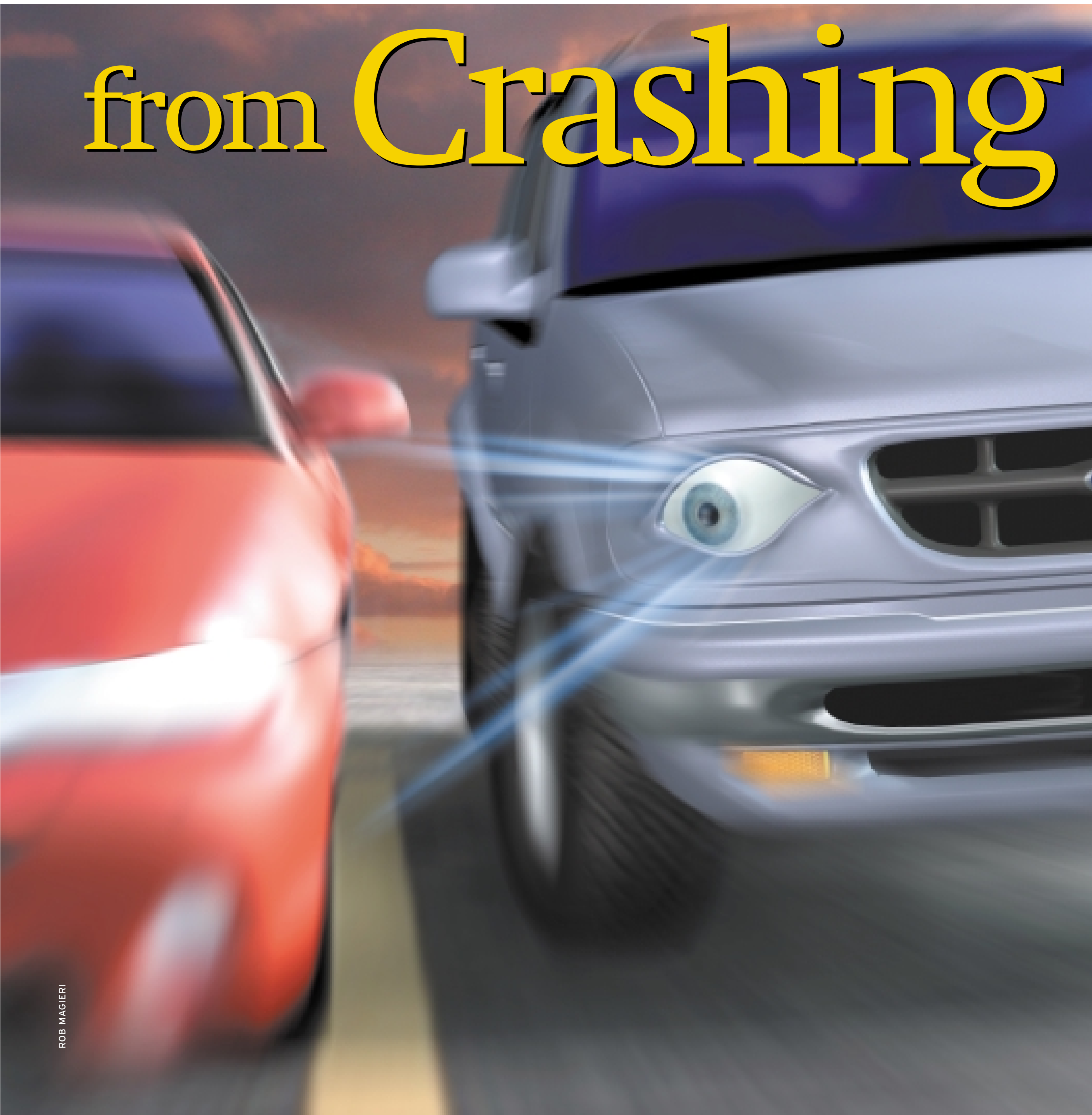
In May 1998, Toyota became the first to introduce an ACC system on a production vehicle when it unveiled a laser-based system for its Progres compact luxury sedan, which it sold in Japan. Then Nissan followed suit with a radar-based system, in the company's Cima 41LV-2, a luxury sedan also sold only in Japan. In September

1999, Jaguar began offering an ACC for its XKR coupes and convertibles sold in Germany and Britain. Like many ACC systems, it is the result of a group effort: Delphi Delco Electronic Systems supplies the radar sensing unit; TRW Automotive Electronics, the brake control; and Siemens, the assembly that manipulates the throttle.

Last fall, Mercedes-Benz and Lexus joined the adaptive cruise control movement. Lexus offers an ACC option for its top-of-the-line LS430; at the moment, it is the only ACC system available in the United States. Mercedes' system is an option on its C-Class and S-Class models, which are available in Europe; it was developed by M/A-Com, Lowell, Mass., and uses a radar made by Filtran Microcircuits Inc., in West Caldwell, N.J.

Although conventional cruise control is a much more popular option in North America than it is in Europe and Asia, none of the Big Three U.S. automakers has an ACC system in production yet. General Motors (GM) and Ford, however, are collaborating on a Collision Avoidance Metrics Project, whose results are expected to influence the companies' early ACC offerings. Both plan to introduce ACC systems for calendar year 2002, GM in a Cadillac, and Ford in a Lincoln. By then, Opel, Saab, and Volvo will have also made systems available as options on some of their cars, according to Raymond Schubert, a researcher at Tier One, a Mountain View, Calif.–based automotive electronics market research firm.

Several automotive electronics firms have also built ACC sys-



ROB MAGIERI

tems, hoping to carve out a niche in a market that is expected to climb above $2 billion a year within a decade. Autocruise, a joint venture between TRW Automotive Electronics Inc., Cleveland, Ohio, and Thomson-CSF in Paris, introduced a radar-based system in March 2000. Eaton Vorad Technologies LLC, Galesburg, Mich., also makes radar-based systems for cars and trucks [see “Big Rigs Need Protection, Too,” p. 44]. Neither offering has yet won a commitment from a major automaker.

Radar versus lidar

All of the ACC systems available today are built around sensors that detect the vehicle ahead through the use of either radar or lidar (light detecting and ranging, the laser-based analog to radar). The choice of sensor presents classic design tradeoffs. Lidar is less expensive to produce and easier to package but performs poorly in rain and snow. The light beams are narrower than water droplets and snowflakes, pushing down the signal-to-noise ratio in bad weather. Which is precisely when you need it most, argues Tony Stewart, a project engineer at Fujitsu Ten Ltd., Plymouth, Mich., which is working on an advanced ACC using radar. Another problem is that accumulations of mud, dust, or snow on the car can block lidar beams.

At present, only one automaker, Lexus, uses a laser-based ACC system, in its LS430 luxury sedan. System engineers have acknowledged lidar’s shortcomings and taken steps to make the system unavailable in situations where the weather may limit its effectiveness. According to the LS430 owner’s manual, the system will automatically shut itself off if the windshield wipers are turned to a rapid setting, indicating heavy rain or snow; if something activates the anti-lock braking system (which helps the driver maintain steering control and reduces stopping distances during emergency braking situations); or if the vehicle skid control system detects the slipping of tires on turns that is common in wet weather.

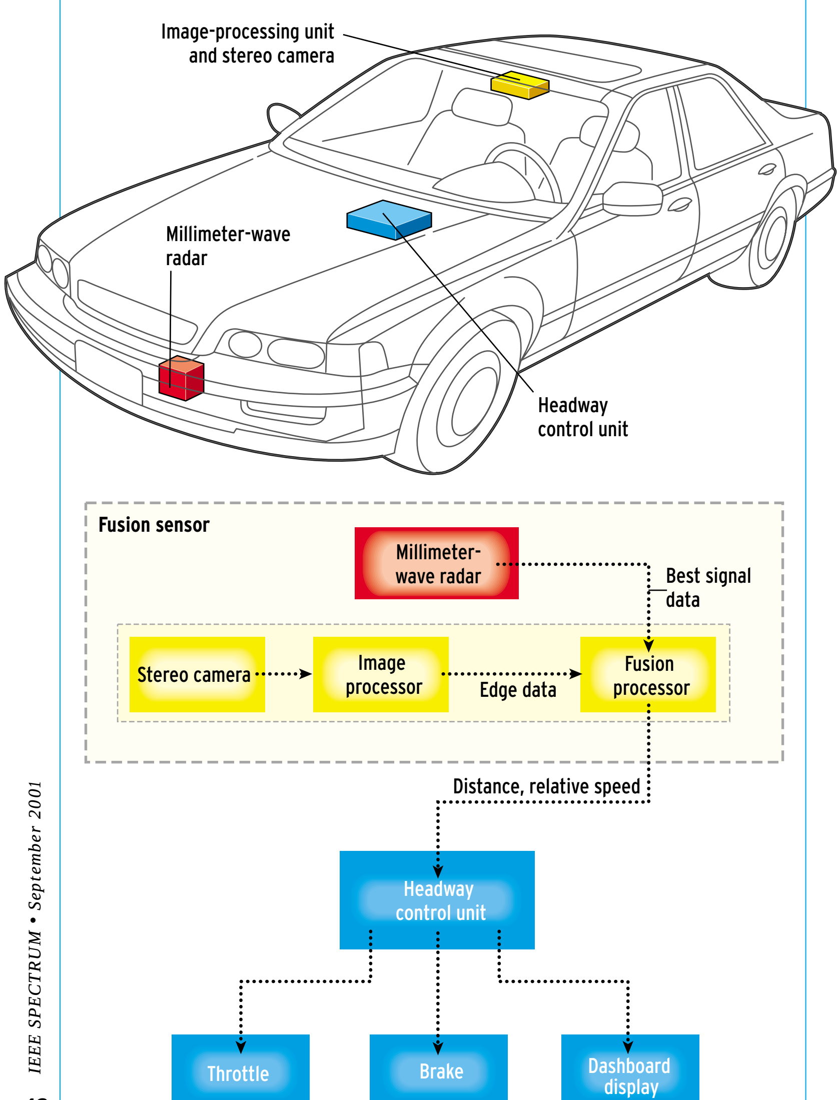
Radar-based systems, on the other hand, can “see” at least 150 meters ahead in fog or rain heavy enough to cut the driver’s ability to see down to 10 meters or less. The choice of radar or lidar depends on the designers’ philosophy: proponents of the laser-based systems insist that a collision-warning system should not work far beyond what the driver can see. To do so, they say, would encourage people to drive too fast in conditions of poor visibility and lead to crashes when the collision-warning system failed to detect an obstacle. Conversely, proponents of radar-based systems argue that the driver needs the most help in conditions of poor visibility.

Radar-based systems employ a variety of sensing and processing methods to determine the position and speed of the vehicle ahead. A fairly simple scheme (like the one used by Mercedes) switches rapidly among three beams by changing feed points along the antenna, creating a scanning effect inexpensively and with no moving parts. The beams are wide enough to ensure that each overlaps those adjacent, providing a combined 12-degree field of view. An advantage is that the wider beams permit the use of a smaller antenna.

More advanced and costlier sensing schemes rely on an antenna that is mechanically scanned and that emits a narrow beam. These systems scan between 64 and 128 points in the radar’s field of view, also typically 12 degrees, so that resolution is much higher than for a three-beam system. The beams are much narrower than in the three-beam models, however, so the antenna has to be larger. And the multiplicity of beams requires much more

Next Generation of Cruise Control

A prototype “fusion processor” from Fujitsu Ten Ltd. depends on optical and radar sensors to move a car automatically at the varying speeds of traffic. A camera and radar report on the width, distance , and speed of objects ahead, and the processor combines the data, feeding it to a unit that controls the car.



STEVE STANKIEWICZ

processing power to handle the streams of data that pour out as the radar scans across the multiple points of focus to determine the leading car's position and speed.

Regardless of the scanning mechanism, the radars typically operate in the millimeter-wave region at 76–77 GHz. The automakers refused to alter the shape or construction of their vehicles to accommodate ACC, so designers had to build systems small enough to be mounted inside a car's front grille. That stringent size requirement in turn demanded a compact antenna, which in turn forced the use of the high frequencies, antenna size being inversely related to frequency. At 76–77 GHz, frequencies are high enough to work with small antennas, yet not so high that the components are exotic and stupendously expensive. A typical automotive radar, produced by Delphi Delco Electronics Systems, of Kokomo, Ind., is roughly the size of two stacked paperback books—just 14 by 7 by 10 cm.

Engineers considered frequencies even higher than 76 GHz, such as 94 and 125 GHz, but the components required are prohibitively expensive at the moment. All the same, engineers have not given up on higher frequencies, which would let them shrink the antennas, whose size dominates the overall system size. Smaller units would give designers more flexibility in the location of the devices. Instead of being centered behind the car's front grill, which is where they must go today, they could be mounted on a car's rearview or side mirrors or near a headlight.

Such leading-edge technologies as monolithic microwave integrated circuits (MMICs), initially developed for military and communications applications, also contribute mightily to compactness. Engineers put an entire radar system on a handful of these circuits. The chip set includes a microprocessor that communicates with a digital signal processor and the radar's scanning mechanism. It feeds a separate control computer, which decides whether to engage the throttle or brakes.

Automakers are now striving to integrate all of these functions into a single chip, said Osman Altan, an engineer at General Motors' Research and Development Center, in Warren, Mich. Such an advance would make the systems cheaper to produce and less vulnerable to interference.

Yet another enabling technology is flip-chip packaging, an advanced and compact method of making electrical connections to an IC. Besides permitting more accurate placement of more numerous chip leads, it lowers production costs and enhances ruggedness and reliability.

Coming: cooperative collision avoidance

Though conventional ACC is still an expensive novelty, the next generation, called cooperative adaptive cruise control, or CACC, is already being tested in California and elsewhere. While ACC can only respond to a difference between its own speed and the speed of the car ahead, cooperative systems will allow two or more cars to communicate and work together to avoid a collision. Ultimately, experimenters say, the technology may let cars follow each other at intervals as short as a half second. At 100 km/h, that would amount to a distance between cars of less than 14 meters (roughly two car lengths).

An experiment to try out these ideas was conducted by researchers at California Partners for Advanced Transit and Highways (PATH), a collaboration between the California Department of Transportation, the University of California, and others. In that trial, a group of three test vehicles used a communication protocol in which the lead car broadcast information about its speed and acceleration to the rest of the group every 20 ms. Additionally, each car transmitted information about its speed and acceleration to the car behind it.

According to Datta Godbole, a former research assistant at California PATH, in Berkeley, the intent of the experiment is to develop systems that allow cars to set up platoons of vehicles in an *ad hoc* fashion. The cars communicate with one another by exchanging radio signals, much as portable electronic devices talk to each other using the Bluetooth wireless protocol. When one car pulls up behind another, the two will scan to determine whether the other is equipped for CACC. The cars will then work out a safe following distance on the basis of their actual performance characteristics—for example, the condition of the brakes of the trailing vehicle. It could be that "you end up having a Porsche or Mercedes limited by the performance of a Pinto," Godbole acknowledged.

> A typical automotive radar is roughly the size of two stacked paperback books—just 14 by 7 by 10 cm

Researchers at the department of electrical engineering and computer science at the University of California, Berkeley, are also working on a platooning architecture, but one in which the following distance is a fixed 1–4 meters between vehicles. The exact distance, determined by a set of control laws, again depends on the state of the least-able vehicle. Other teams are working on control laws to handle various other situations, as, for example, when a car joins or leaves the platoon, when a platoon member changes lanes or enters or exits the freeway.

Stop-and-go, automatically

Meanwhile at Fujitsu Ten Ltd., Plymouth, Mich., engineers are working toward another vision of the future of adaptive cruise control—one targeted squarely at the realities of driving on often congested urban and suburban highways. Fujitsu Ten has demonstrated a prototype system for so-called stop-and-go adaptive cruise control. Ordinary ACC systems maintain safe distances between cars at speeds above 40 km/h, whereas Fujitsu Ten's system will work primarily at lower speeds in heavy traffic. If the car in front of it stops, it will bring a vehicle to a complete stop. Afterward, it will not re-engage the throttle—that's up to the driver—but as soon as the throttle is engaged, it will accelerate and decelerate along with the leading car over any range of speeds between zero and the cruising speed set by the driver.

This so-called fusion sensor gets its name from the linking of the enhanced millimeter-wave radar from Fujitsu Ten's first-generation ACC system to a 640-by-480-pixel stereo camera with a 40-degree viewing angle. The camera, which uses two CMOS image sensors spaced 20 cm apart, is mounted inside the car between the windshield and the rear-view mirror [see illustration, p. 42].

The radar and the cameras work together to track the car ahead and distinguish it from extraneous nonmoving objects more rapidly than would be possible with either alone, according to Keiji Fujimura, a senior manager at Fujitsu Ten. While the radar homes in on the lead car's rear bumper, the stereo camera is constantly measuring the widths of all the items in its wide field of view [see figures opposite]. To calculate them, it uses an algorithm based on the detection of vertical edges and the distance. Bridges, trees, and other stationary objects that are much wider or narrower than a car are quickly rejected as reasons for the system to apply the brakes. The concentration on vertical edges also helped hold down the cost and complexity of the optical system.

The camera's wide field, along with the radar's wider-than-average 16-degree field of view, enhances the system's

Big Rigs Need Protection, Too

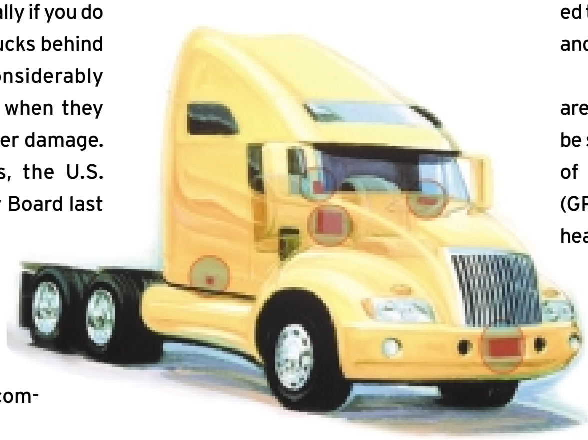
Collision avoidance is still largely futuristic in cars, but it's been around for years on big rigs. Since 1994, Eaton Vorad Technologies LLC, Galesburg, Mich., has equipped more than 10 000 trucks with collision-warning systems that alert the driver when the vehicle ahead is dangerously close.

It's comforting news, especially if you do a lot of highway driving with trucks behind you. After all, trucks take considerably longer than cars to stop. And when they crash, they can wreak far greater damage. For those and other reasons, the U.S. National Transportation Safety Board last June asked the U.S. Department of Transportation to develop performance standards for collision-warning systems on large trucks and to make them mandatory on all new commercial vehicles.

The rigs outfitted with the Eaton Vorad system belong to 50 large fleets operated by freight companies and large manufacturers. The unit, known as EVT-300, uses radar to detect objects up to 107 meters ahead, while other radars on both sides of the truck's cab pick up objects in the blind spots alongside the vehicle. A beeper and light-emitting diodes issue different warning levels based on the proximity of the object in the truck's path.

Since 1998, Eaton Vorad has also offered a radar-based adaptive cruise control system as an option to the EVT-300. This add-on, called SmartCruise, maintains the interval between a truck and the vehicle ahead by changing gears or by applying the brakes.

Fleet owners say that data collected over hundreds of millions of kilometers of highway service with these systems suggests that they reduce accident rates by as much as 70 percent. Encouragingly, drivers report that over time, they become conditioned to maintain greater following distances. The US $2000–$3000 cost of the



Trucks equipped with the EVT-300 collision-warning system have sensors on the bumper and below each door. Displays warning the driver of frontal and side collisions are inside the cab, while the system's central processor sits just above the engine block.

EATON VORAD

units is quickly repaid by the savings from lower insurance premiums, fewer accidents and repairs, and even by lower fuel costs due to changes in the drivers' braking patterns.

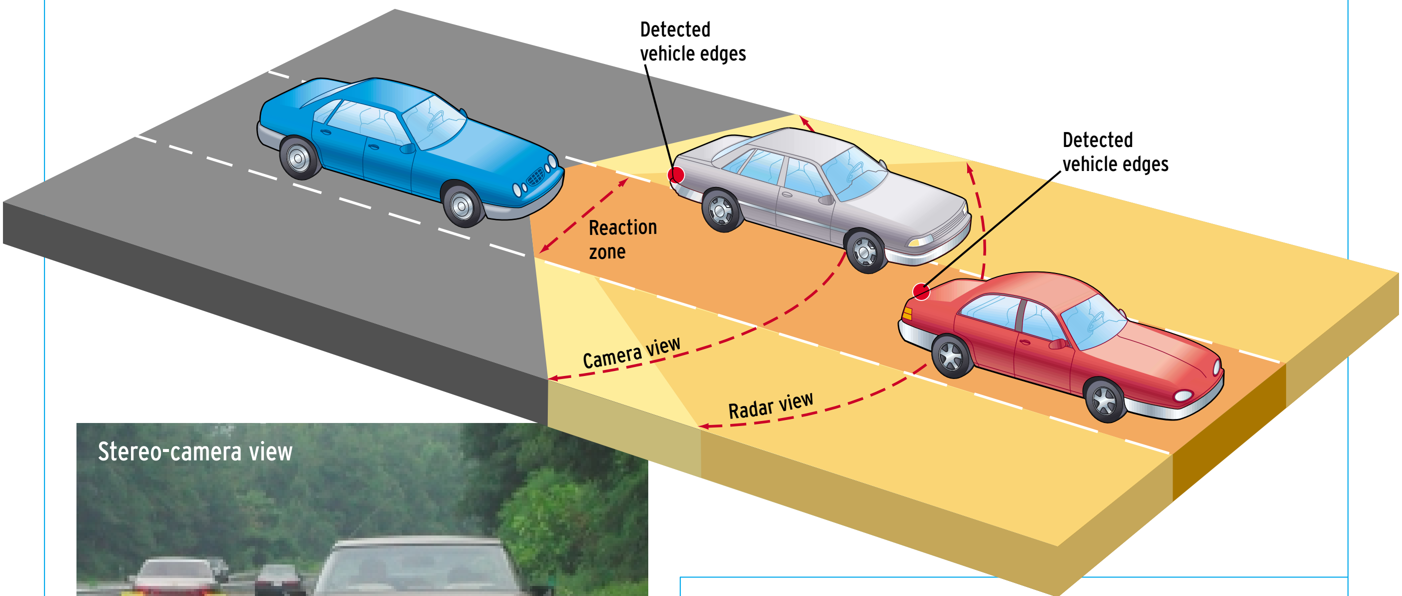
Other work vehicles will also soon be benefiting from collision-avoidance. Consider snowplows: in the long, bitter winters of the north-midwestern United States, they must often slog through conditions in which visibility is so bad that road markings, shoulders, and obstacles like divider strips and bridge abutments are completely obscured. A project at the Intelligent Transportation Systems Institute at the University of Minnesota has put sophisticated electronics in the cab of a 30-ton prototype snowplow that will warn the driver about nearby objects, including cars. Advanced plows aren't limited to Minnesota, either—Wisconsin has eight and Iowa, 18.

But four of Minnesota's $100 000 plows are in a class by themselves. They will each be studded with an additional $10 000 worth of gadgets. Global positioning systems (GPSs), radar, on-board databases, and heads-up displays will provide a virtual real-time image of the road, extending even to its unseen obstacles. GPS will locate the truck to within 25 meters, and a radar, tuned to a system mounted on a nearby transmission tower, will give a reading on the plow's position that is accurate to within a few centimeters. The display, reminiscent of a portable videogame, uses the databases to provide an image of road features such as turns, intersections, and medians. Meanwhile, data from vehicle-based radar shows nearby objects as small rectangles on the screen.

"We had 20 operators drive this truck with curtains on all the windows," said John Scharffbilig, highway maintenance supervisor for the Minnesota Department of Transportation, Saint Paul. "They each drove a four-mile course [6 km] with hairpin curves, right-angle curves, and an S-curve, and we had only one small incident." Scharffbilig, who was a snowplow driver for 22 years, said, "It's like going from a typewriter to a computer." —W. D. J.

Following the Leader

The Fujitsu Ten system keeps a safe distance behind cars in its lane [reaction zone] by combining radar data on distance with stereo-camera data on the size of objects. The camera derives the width of cars by detecting their edges [red dots, and yellow boxes in the photo]. Objects that are too wide, like a bridge abutment, are ignored. The system's wide field of view allows it to continue tracking vehicles around curves.



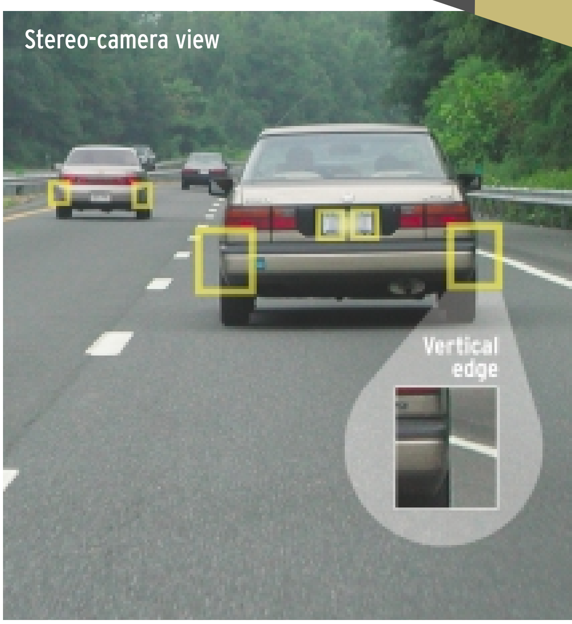


ILLUSTRATION: STEVE STANKIEWICZ
PHOTOGRAPH: MICHAEL R. VELLA

performance on tight curves, enabling it to continue tracking the lead car as the latter enters the curve and moves to one side or the other. Fujitsu Ten plans to improve the unit with a phased-array radar that "scans" by altering the relative phase of the signals emitted from a group of antennas and, consequently, the direction of the emitted beam. This beam-shifting occurs almost instantaneously, because no component has to be physically moved. In a collision-avoidance system, overall reaction time could be reduced. There are other advantages; beam-shifting in a phased array is more precise than scanning an antenna mechanically, and the unit lasts longer because no movement means no wear. Better still, the shape of the beam, which defines the scanning area, can be changed on the fly in response to changing road conditions, said Fujimura.

The system has worked well in trials, Fujimura added; nevertheless, it is not slated to go into production until 2004.

Like its competitors, Fujitsu Ten is hoping to grab a share of a global market for first-generation ACC that is expected to reach $2.4 billion by 2010. By 2006, collision avoidance will be in 17 percent of new cars in Europe, 14 percent in Asia-Pacific Rim, and 13 percent in North America, according to Morris Kindig, president of Tier One.

Robo-chauffeur?

As collision avoidance becomes first commonplace and then sophisticated, the role of the driver will change. Within a decade or so, the drivers of the most advanced cars will only have to steer. Eventually, people might not be entrusted even with that task, at least on limited-access highways. In fact, a decade ago engineers at Carnegie Mellon University (CMU), in Pittsburgh, and in a Daimler-led research program called Vision Technology Application (VITA) tested cars that largely drove themselves. CMU and VITA vehicles logged thousands of highway kilometers, most of them with a driver sitting vigilantly behind the steering wheel but not touching it.

The Intelligent Vehicle Initiative in the United States and the Ertico program in Europe are among dozens of groups working on technologies that may ultimately lead to vehicles that are wrapped in a cocoon of sensors, with a 360-degree view of their environment. Nearby vehicles would be in constant communication and act cooperatively, enabling groups of cars to race along like train cars, almost bumper to bumper, at speeds above 100 km/h.

It will probably take decades, but car accidents may eventually become almost as rare as plane crashes are now. The automobile, which transformed the developed world by offering mobility and autonomy, will finally stop exacting such an enormous cost in human lives. ●