Vehicle Platooning and Automated Highways

The eight-vehicle platoon demonstration at the National Automated Highway Systems Consortium Technical Feasibility Demonstration, held in San Diego from August 7-10, 1997, successfully demonstrated the technical feasibility of operating standard automobiles – Buick LeSabres– under precise automatic control at close spacings, at highway speeds. Riders experienced real travel in a fully automated AHS vehicle, and were shown that comfortable, high-capacity, automated travel is technically feasible in the near future.

The platoon demonstration was designed by researchers at the California PATH program to show how vehicle automation technology can be used to make a major contribution to relieving traffic congestion. The eight Buicks operating in tight coordination showed how an automated highway system can provide a significant increase in highway throughput (vehicles per lane per hour moving along the highway).

Since platooning enables vehicles to operate much closer together than is possible under manual driving conditions, each lane can carry at least twice as much traffic as it can today. This should make it possible to greatly reduce highway congestion. Also, at close spacing aerodynamic drag is significantly reduced, which can lead to major reductions in fuel consumption and exhaust emissions. The high-performance vehicle control system also increases the safety of highway travel, reduces driving stress and tedium, and provides a very smooth ride.

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Longitudinal Control

In the platoon demonstration, eight vehicles traveled in close coordination under fully automated longitudinal and lateral control. The cars maintained a fixed spacing of 6.5 meters (21 feet) between themselves at all speeds up to full highway speed. The spacing was maintained with an accuracy of +/- 10 cm. (4 inches) during cruising and +/- 20 cm. (8 inches) during maneuvers like acceleration and deceleration. In the future, improved spacing accuracy achieved by the longitudinal control system should enable the spacing to be reduced to less than 2 meters (6.5 feet).

This short spacing between vehicles can increase the throughput of the highway, allowing it to carry as much as twice or three times as many vehicles than now. The other major advantages of the platooning system are increased safety and fuel efficiency. Safety is increased by the automation and close coordination between vehicles, and is enhanced by the small relative speed between the cars in the platoon. Because the cars in the platoon travel together at the same speed, a small distance apart, even extreme accelerations and decelerations cannot cause a serious impact between the cars. The limited spacing constrains the maximum relative speed between cars in the event of a crash, and ensures the safety of passengers.

Accurate intercar spacing in the platoon is achieved by the longitudinal control system through the use of radar and radio communication between cars. Each car in the platoon uses its radar to measure the distance to the preceding car. The radio communication system provides each car with broadcast information on the velocity and acceleration of the preceding car and the lead car of the platoon. All of these signals are used by the longitudinal feedback control system to continuously determine the desired acceleration of each car. The throttle or the brake is then used to provide the desired acceleration. A knowledge of the dynamic behavior of the throttle and brake actuators ensures that they are expertly controlled so that the desired acceleration is achieved very accurately. The longitudinal control system updates the actuators at a rate of 50 times per second.

The platoon demonstration also showed how a car can leave or join the platoon. The radio communication system is used to coordinate such maneuvers within the platoon. A car that desires to leave the platoon informs the lead car, and is then given permission to drop back to a larger spacing from the preceding car. The car immediately behind also drops back to a larger spacing. The exiting car then makes an

At Demo ’97, the eight vehicles of the PATH platoon traveled at a fixed separation distance of 6.5 meters (21 feet) at all speeds up to full highway speed. At this spacing, eight-vehicle platoons separated by a safe interplatoon gap of 60 m (about 200 ft.) and traveling at 65 mph would represent a “pipeline” capacity of about 5700 vehicles per hour. Reducing this by 25% to allow for the maneuvering needed at entry and exit points corresponds to an effective throughput of about 4300 vehicles per lane per hour. Throughput under normal manual driving conditions at this speed would be approximately 2000 vehicles per lane per hour.

Such short spacing between vehicles can produce a significant reduction in aerodynamic drag for all of the vehicles (leader as well as followers). These drag reductions are moderate at the 6.5-meter spacing of the Demo, but become more dramatic at spacings of half that length. Wind-tunnel tests at the University of Southern California have shown that the drag force can be cut in half when vehicles operate at a separation of about half a vehicle length. Analyses at UC Riverside have shown how that drag reduction translates into improvements of 20 to 25% in fuel economy and emissions reductions.

The tight coordination of vehicle maneuvering is achieved by combining range information from a forward-looking radar with information from a radio communication system that provides vehicle speed and acceleration updates 50 times per second. This means that the vehicles can respond to changes in the motions of the vehicles ahead of them much more quickly than human drivers. As a result, the space between the vehicles is so close to constant that variations are imperceptible to the driver and passengers, producing the illusion of a mechanical coupling between the vehicles.

PATH Engineer Jurgen Guldner reads the newspaper at nearly 40 mph.

The vehicle-vehicle communication capability is used to coordinate maneuvering. These maneuvers include lane changing, in which a vehicle safely coordinates its lane change with adjacent vehicles, so that they do not try to occupy the same place at the same time, and platoon join and split maneuvers — decreasing the space between vehicles to form a platoon and increasing the space to separate from a platoon.

Tight coordination among vehicles also facilitates responses to malfunctions, enabling all vehicles in a platoon to learn about a malfunction within a fraction of a second, so that they can respond accordingly. The vehicles are equipped with malfunction management software, to automatically implement such corrective actions as increasing the separation between vehicles while warning the drivers.

The control system has also been designed with careful attention to passenger ride quality. Both the lateral (steering) and longitudinal (speed and spacing) control systems have been designed, tested, and proven to have higher performance than even highly skilled human drivers. The lateral control system keeps the vehicle to within a few inches of the lane center under virtually all conditions, which is much more accurate than human drivers' steering. The longitudinal control system maintains speed and spacing accuracy that exceeds that of all but virtuoso race-car drivers.

The accuracy and fast response of the longitudinal control system provides a reassuring, smooth ride. Although some people are initially startled by the "tailgating" aspect of vehicle following at close separations, most of them quickly adapt and develop a sense of comfort and security because of the constantly maintained separation.

Fully automated LeSabre corners on PATH test track.

automated lane change to the adjacent lane. All the cars in the rear of the platoon then speed up to join those in the front, so that correct spacing between all cars is restored.

In the San Diego demo, the car that split from the platoon rejoined it after a mile of cruising in the other lane. The car that had split slowed down and matched speed at the tail of the platoon, changed back to the lane the platoon was in, and then accelerated to rejoin the platoon as its very last car. This is the way a car entering the system at an onramp would join a passing platoon.

Lateral Control

For a vehicle to follow the road, the road has to be first marked by some indicators that define its boundaries. The vehicle then employs appropriate sensors to measure the corresponding physical properties of the indicators and to determine its location with respect to the road markings. Onboard intelligence, based on the relative locations, commands the steering actuator to steer the vehicle and follow the road.

The PATH automatic steering control system uses magnetic markers buried along the road center 4 feet apart to define the roadway. By alternating the polarities of the magnetic markers, they also transmit such roadway characteristics as upcoming road geometry information, milepost locations, and entrance and exit information to the vehicle. Six three-axis fluxgate magnetometers, developed by Applied Physics, located below the front and rear bumpers of the vehicle, detect the magnetic field of the magnets. A signal processing algorithm, by comparing the measured magnetic strength to the 'magnetic field map' of a magnet and eliminating the background noises, determines the relative position of the vehicle to the road center. This information is then provided to a Pentium computer to determine the desired steering command through a robust algorithm. A DC motor added to the steering column, developed by Delphi Saginaw, steers the vehicle according to the steering command.

The result is an automatic steering system that tracks the roadway center with less than three inches of error with good passenger comfort. The major advantage of such system is that it offers a relatively simple, potentially economical, and very robust automatic steering control system. The system works equally well under inclement conditions such as rain, snow, and low visibility.

Fault Management

A very important feature of the vehicle control system is the automated fault management system that has been implemented on the cars. The fault management system will both detect and handle failures in the sensors and actuators on the vehicles. Failures are typically detected within a fraction of a second of the time they occur. Some failures are handled without any perceptible change being noticed by the passengers. In some cases, however, for instance in the case of a radio communication system failure, the spacing between some cars in the platoon is enlarged to as much as 15 meters. In the rare event of an actuator failure, the driver of the car will be informed that his intervention is necessary.

When a failure is detected in any vehicle, appropriate action messages are broadcast to all the vehicles in the platoon to coordinate their response. Even a malfunction like a complete breakdown of the computer system in a car will trigger a fault management response in the other cars in the platoon, thereby avoiding a crash. This is possible because a computer or communication system breakdown in any car causes the car behind it to stop receiving appropriate radio messages, thereby enabling it to detect that a fault has occurred. The fault management system ensures greater safety even in the case of a malfunction in any of the hardware.

The human/machine interface on the Demo LeSabres has been carefully designed to enhance user acceptability. The steering-wheel control buttons can be used to activate and deactivate automation functions, and the flat-panel display in the center of the instrument panel provides timely status information. The latter is important so that the driver can be given assurance during fully automated driving that the system really “knows” what it’s doing. Maneuvers that might be surprising are indicated in advance on the display so that there are no surprises and so that vehicle movements will seem natural and logical.

Although the platoon scenario at Demo ’97 in San Diego did not include the full range of functions that would be needed for an operational automated highway system, it did include capabilities that would not be needed in normal AHS operations. For example, the entire platoon started from a stop at the start of the demo, and decelerated to a stop at the end, because of the physical constraints of the Demo site. In an operational system, individual vehicles would accelerate on the onramps to merge into the traffic stream, and would decelerate on the exit ramps after lane changing out of a platoon, while the mainline traffic would be flowing continuously. Since the I-15 HOV facility does not have intermediate on- and off- ramps, the entire platoon started and stopped together.

PATH researchers designed the operational concept and control systems for the platoon scenario, and specified the hardware performance requirements. They developed the magnetic reference sensor system for lateral control, the electronic throttle actuation system, the communication protocols for vehicle-to-vehicle communication, and the malfunction management software. PATH researchers also integrated all the in-vehicle software, and debugged and tested the complete vehicle control system.

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California PATH—Partners for Advanced Transit and Highways—is a joint venture of the University of California, other public and private academic institutions, Caltrans, and private industry, with the mission of applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution, and energy consumption.