Intelligent Cruise Control and Roadside Information

The on-board Autonomous Intelligent Cruise Control system controls a vehicle's speed according to the driver's desire and the speed of and distance to the preceding vehicle. Volvo developed, realized, and tested such a system, with enhancements. This system offers a one-directional short-range system for vehicle-vehicle and roadside-vehicle communication and considerations for recommended speed, limits, and traffic signals. It is potentially a key element in linking and integrating the driver-vehicle-infrastructure in future intelligent transportation systems.

An on-board vehicle system designed to control the longitudinal velocity at a driver's set value as well as the velocity of and the distance to a preceding vehicle offers several advantages. Compared to the traditional cruise control system found in many vehicles today, the Autonomous Intelligent Cruise Control, or AICC, system uses information to adjust the vehicle's velocity to that of the preceding vehicle and keep it at a safe distance. Drivers will appreciate the comfort and safety offered by these extra functions. This system encourages smoother driving and, especially when the controllers are well tuned, reduces fuel consumption and the amount of harmful pollutants expelled into the environment, and better harmonizes traffic since acceleration and braking are also reduced.

Adding short-range vehicle-to-vehicle and roadside-to-vehicle communication to an AICC system lets drivers receive more accurate vehicle and traffic data at an earlier stage. (See Figure 1.) Drivers and their vehicle systems can access information about the status of surrounding traffic and take earlier, appropriate actions.

Systems of this sort are currently under intensive study and development in the Road and Traffic Informatics (RTI) programs in Europe, the United States, and Japan.1,2

System description and requirements

Simply described, AICC requires, besides the ordinary vehicle sensors and systems, a target sensor to detect and measure the distances to preceding vehicles. Measurement of the relative velocity is an advantage but not a prerequisite. AICC must contain some intelligence and computing power for the evaluation and interpretation of sensor data, determination of appropriate control actions, and selection of information to the driver. The actual velocity control requires local control systems for accelerating and braking. A simple and sufficient man-machine-interaction unit exchanges commands and information with the driver, and a computer network or bus lets data flow between the hardware units. Since this is a real-time multievent application, real-time multitasking software should be used.

Target sensor. The zone in front of the AICC vehicle, of relevance for its velocity control, is not trivial to define. It depends on the demand one has of the system, the handling properties of the vehicle, the actual road conditions (for example, friction between road and tire, road curvature), and the velocity of the vehicle. Since AICC is designed primarily for country and highway driving (not heavy urban traffic), a target sensor should cover a zone of relevance defined as three
lanes at a distance of zero to, say, 150 to 300 meters; see Figure 2. With a coverage of three lanes, the lane of the AICC vehicle and the lanes to the left and to the right can be scanned. Scanning the adjacent lanes is necessary as vehicles may be overtaking the AICC vehicle and moving into its lane. The range of 150 to 300 meters strongly depends on the conditions under which the AICC system should operate. The well-known formula

\[ d = v \cdot T + \frac{v^2}{2r} \]

expresses the distance \( d \) required to stop a vehicle at initial velocity \( v \). The first term, \( v \cdot T \), is the distance traveled during the reaction time (pure delay) of the driver and/or the system. The second term, \( \frac{v^2}{2r} \), is the braking distance required when applying the retardation value \( r \). As an example, consider the case \( v = 120 \text{ km/h} \) (33.3 meters/s), \( T = 1.0 \text{ second} \), and \( r = 2 \text{ meters/s}^2 \) (maximum retardation for comfort). The braking distance for this case is 311 meters. Hence, if the AICC system must be able to stop in front of static obstacles from an initial velocity of 120 km/h, the target sensor needs to have a range of more than 300 meters.

From a systems point of view, it is natural to require a target sensor that covers a zone of relevance of 150 to 200 meters. The sensor should be able to detect objects from motorbikes to trucks and to measure the distance and the direction to them. As an advantage, the relative velocity can be measured independently, that is, not constructed as a function of distance measurements.

The sensor should be intelligent enough to filter out background noise and disturbances such as echoes from roadside railings and road signs. An ideal target sensor is one that delivers only the distance, the angle, and the relative velocity to objects like motorbikes, cars, and trucks in the zone of relevance. The sensor must function under clear weather conditions as well as in rain, fog, and snow. Today, scanned or multibeam radar and laser systems appear to be the most promising and reasonable choices to implement these needs.

**Signal processing and control unit.** The hardware unit is a computer that executes algorithms for signal evaluation, interpretation of traffic, decision and determination of control actions, and choice of information to the driver. The signal processing algorithms use the signals from the target sensor and from vehicle sensors as input (velocity, steering angle, yaw rate). Signal processing reduces the noise level of the signals and estimates the states of the AICC vehicle and all other vehicles detected in the zone of relevance. This means that, among others, the two-dimensional velocities of the vehicles and their relative positions have to be estimated.

The control algorithms use the estimated states produced by the signal processing and the driver's set speed as input. Based on these data, the control algorithm determines the correct restriction for the longitudinal velocity (driver's set speed or a preceding vehicle) and calculates the control actions to be implemented by the actuators. The physical form of the control actions depends on how the AICC system is decomposed. A natural decomposition leads to control actions of either velocity or acceleration (positive and negative) commands.

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**Figure 1. Intelligent cruise control system extended with communications for roadside information.**

**Figure 2. Zone of relevance.**
Actuators for velocity control. The AICC system must have local control and actuator systems to adjust the vehicle's velocity in an efficient and smooth fashion. Inputs to these local systems are the control commands from the control unit (velocity, acceleration, and retardation commands).

Two systems are used to fulfill these requirements. An electronic throttle system can accelerate and keep the velocity constant. It can be thought of as a smart actuator that controls the actual acceleration or velocity close to the commanded one. The other is an electronic braking system in the form of a smart actuator that adjusts the actual retardation so it is sufficiently close to the commanded one.

Man-machine-interaction. This unit exchanges commands and information between the driver and the AICC system in a simple way at a sufficient level. The driver should be able to give the following commands and values to the AICC system:

- activate system,
- deactivate system,
- reactivate system,
- set speed value,
- increase set speed, and
- decrease set speed.

This input can, of course, be facilitated in many ways. Say the driver is not allowed to choose combinations of the functions of the AICC system (it is either turned off or turned on with all functions in operation). It seems most reasonable then to use the commonly accepted input pushbuttons of the traditional cruise control system for the AICC system also.

The driver must also be able to override the system manually at any time. Therefore, when wanting to go faster (pressing the accelerator pedal) or slower (pressing the brake pedal), the driver overrides the system. Note that the driver is fully responsible for the vehicle and its operation and, consequently, must have the overall control of it.

At any moment the status of the AICC system and its operation should be clear to the driver. Therefore, it must at least deliver the following information:

- verification of the driver's input,
- mode of operation (passive or active), and
- object for control (driver's set speed or preceding vehicle).

Today, no clear recommendations can be given on the content and form of this information to the driver. Displays and artificial voice are, of course, considered as candidates for output media.

Network and software architecture. The units in the AICC system have computing needs and capacities, and they continuously exchange information and commands. Implementing such a system requires an efficient network and software architecture. The philosophy of system design today is to distribute the tasks, with the corresponding computing capacity, and to connect these local units (or local nodes) with a common data bus. Variables and signals used only within a local unit are restricted to that unit, while variables and signals of relevance to more than one local unit are passed on to the common data bus and accessible to any connected unit. Figure 3 describes this structure.

Each unit must have an interface layer of hardware and software toward the bus to satisfy the specification of the common data bus. Furthermore, global variables and protocols for their transfer have to be defined. The implementation of application software, limited and local to a unit, should be possible with the only restriction that it does not disturb the transfer of the common variables at the data bus.

Short-range communication. By definition, the truly autonomous intelligent cruise control system uses only passively reflected waves from the target sensor in its detection and measurement of preceding vehicles. The advantage of this system is that it does not require equipment mounted on other vehicles for their cooperation. The drawback is that the data received is not always reliable; often the noise level is high, and echoes from objects along the roadside may disturb the measurements and target tracking.

Adding a system for short-range communications, SRC, between vehicles and between the roadside and a vehicle can improve the detection and measurement of preceding vehicles and also extend the functionality of the AICC system. It can transfer absolute or relative positions and vehicle state data from vehicle to vehicle as well as data from roadside equipment, for example, speed limits, status of traffic signals ahead, curvature of bends in the road. With this subsystem, the AICC system can more accurately adjust the vehicle's velocity. The SRC system can be incorporated as just another sensor of velocity restrictions within the AICC. With a structure of the hardware and software as just explained, it is quite easy to include the data from this sensor.

Volvo's AICC system

The AICC system we developed and designed assists drivers in adapting their speeds with regard to
the desired cruise speed,
- the distance to and the velocity of the preceding vehicle,
- speed recommendations and limits, and
- traffic signals and Green Wave systems. (A Green Wave system constitutes a number of coordinated traffic signals yielding green periods at the arrival of vehicles traveling in compliance with the recommended speed.)

Note that the Volvo AICC system has functions similar to those described in Figure 1.

Though the system structure largely follows that already described, it differs in one major way. Our AICC system is equipped with a transponder-based SRC system for acquisition of data from preceding vehicles and the roadside.

Vehicle. The vehicle equipped with our AICC system (pictured in Figure 4) is a standard 1991 Volvo 960 model with electronic control of the gear box.

Target sensor. The autonomous operation of the AICC system uses a target sensor made by Leica® and consisting of five fixed, nonoverlapping infrared beams. Each beam has a range of 150 meters and an angular coverage of 1.5 degrees, horizontally and vertically. Since the beams are not active simultaneously during measurement, it is possible—by knowing which beam caused a received echo and measuring the time of flight—to obtain the distance and angle (crude, in multiples of 1.5 degrees) to the reflecting object. The sensor cannot distinguish between objects separated less than 5 meters longitudinally, and it delivers the measurements corresponding to the closest object (it yields the first and often strongest echo). The sensor can detect objects the size of motorbikes, cars, and trucks. It also easily relays echoes from road signs and other objects along the roadside. Relative velocity is not available from this sensor.

Short-range communication. To transfer data from the preceding vehicle and the roadside, our AICC vehicle uses a transceiver/transponder-based SRC system. The Swedish Institute of Microelectronics developed this system, named Compose, within the Swedish RTI program. (COM stands for communication and POS for position.)

In the AICC vehicle a transceiver unit, mounted in the front, transmits 17.5-GHz microwaves. Any transponders, in the rear of preceding vehicles and as beacons along the roadside, receiving the microwaves amplify the magnitude and modulate the frequency of the waves before reflecting them. The modulation allows the reflected wave to carry data. The transceiver unit measures the phase shift of the reflected wave and its delayed arrival between three patched antennas and determines the distance and angle to the transponder. Therefore, both measurements of the transponder position and data transfer are possible with the Compose system.

The transponder modulates the frequency according to either a programmed static data set in the transponder (static transponder) or data fed into the transponder continuously from an external device (dynamic transponder). The static transponders mainly supply static roadside information, while the dynamic transponders transmit time-variant data, for example, vehicle state data, status of traffic signals, and Green Wave periods.

In our AICC system, the major task of the Compose system is to obtain speed recommendations and limits, traffic signal status, and other road sign information.

Signal processing and control. We developed and implemented model-based methods for the signal processing of sensor data and decisions and determinations of control actions in the signal processing and control unit of the AICC system.

As described earlier, the signal processing unit takes the target sensor data and—provided, of course, that the vehicle is equipped with a transponder—the data transmitted by the Compose system from the preceding vehicle as input. The signals from the sensors in the AICC vehicle (speed, steering angle) also become inputs. State estimators, constructed from dynamic models of the movement of the AICC vehicle and preceding vehicles, use these inputs to estimate the states of the AICC and preceding vehicles. These extended Kalman filter state estimators combined with gating techniques initiate, track, and delete model states of target vehicles.

The control unit has to take into account the following five restrictions or control objectives:

- driver's desired cruise speed,
- distance to and velocity of the preceding vehicle,
- actual speed limit,
- speed limit ahead, and
- traffic signal ahead.

The separate realization of each of these five restrictions is a control problem in itself; some are not at all trivial to fulfill.

Figure 4. Volvo's AICC demonstrator vehicle.
Furthermore, the combination and simultaneous execution of each requires a well-structured control unit. Note that the first four restrictions imply upper bounds on the velocity and acceleration of the AICC vehicle. The fifth restriction implies an upper and a lower bound on the velocity trajectory of the AICC vehicle so it can pass the traffic signal during a green period.

Since a velocity change of the AICC vehicle can be achieved by an acceleration command to the actuators, it is natural to design separate regulators for each of the five restrictions—whose outputs are acceleration commands. The outputs from the first four regulators will be the upper bounds on the permitted acceleration, while the fifth regulator will yield an interval for the acceleration.

Finding the minimal acceleration command among those from the five regulators lets us find the restriction that overrules the other four restrictions and determine which control command should be implemented. This procedure has several advantages. Each regulator can be separately designed to meet the corresponding restriction or criteria. Viewing the acceleration command instead of the actual velocity restriction implies better prediction of how the state will satisfy the restriction. Furthermore, this structure is flexible in the sense that other restrictions can be incorporated in the same fashion, for example, safe driving through a sharp bend with preinformation about the curvature and road/tire friction.

**Actuators for velocity control.** For the actual control of the longitudinal velocity, we installed two local control and actuator units in the AICC vehicle. These are a throttle system from Hella and a braking system from Bosch; both are electronically controlled. The throttle system can be operated in three different modes, yielding a choice between the following desired control commands: speed, acceleration, and throttle angle.

The braking system is basically the Bosch ABS model with an electronically controlled plunger system above the ABS level. (The ABS function guarantees antilocking of the brakes. Since the AICC operates above the ABS level, the antilocking function is kept intact.) It can be operated in either of the two control command modes: desired retardation or desired brake pressure.

**Man-machine-interaction.** The MMI technique in our current AICC system has not been finally developed or adapted to the driver's need and ability. We used the pushbuttons in the traditional cruise control system for the input of the driver's commands and set values. These are:

- activate system,
- deactivate system,
- reactivate system (resume),
- set speed value,
- increment set speed, and
- decrement set speed.

When the driver pushes the set button to activate the system, the set speed value is taken as the actual velocity of the vehicle simultaneously. The driver can override the AICC system at any time by pressing the gas pedal or the brake pedal.

Information from the system to the driver is shown as symbols (see Figure 5) on a color display mounted in the dashboard. Basically, the display shows information regarding the four restrictions of actual speed limit, driver's desired cruising speed, traffic signal ahead and its green period, and the distance to and the velocity of a preceding vehicle when they are potentially in force. The display indicates the symbol corresponding to the restriction the control unit has chosen by outlining it in black borders.

This information lets drivers see that the system has interpreted the situation correctly and that it takes the appropriate control actions. The displayed information also allows the system to operate in an informative mode. That is, the AICC system only delivers the information to the driver, who in turn must manually control the velocity of the car. The AICC system, in this mode, does not implement any control actions. We plan to use and examine this mode in the development phase. The display shows road signs that do not necessarily contain information for AICC velocity control but are relevant to the driver for the safe operation of the vehicle. As an example, the upper-right corner of Figure 5 displays the road sign for a sharp bend.

We do not expect nor intend this MMI description to be the one used in a final AICC system; we designed and used it only for the purpose of development.

**Network and software architecture.** A common controller area network (CAN) carries out the information exchange among the components and subsystems of our AICC system. The software is divided into three layers. The top application layer contains the application programs (signal...
processing, controllers), which are implemented in the form of C processes. The next layer provides real-time, multitasking services to the application programs. This layer uses a vehicle distributed executive (VDX), which is an operative software for the organization of distributed real-time processes and the network communication between them. Finally, a network layer connects the VDX to the CAN network. Though use of the various layers has many purposes, one is worth mentioning: The application programmer should not have to bother with multitasking and network services.

**Linking to the infrastructure**

The AICC is in itself truly an interesting and promising system. However, its value can be further enhanced by using the SRC link to pass information from the infrastructure to the AICC vehicle and its driver. A requirement is, of course, that the roads and streets are equipped with transponders yielding sufficient and necessary information.

The system requires two basic types of information: static and time variable (dynamic). The static information (speed limits, curvature of bends, warnings of school areas) can be preprogrammed into self-contained transponders that only require a power supply. The dynamic information (road conditions, recommended speeds, traffic signal status) is either directly generated by some smart sensors or provided by a local or regional traffic management center. Both have a data link to the appropriate transponders to distribute this information to passing vehicles.

As an example, consider the case of traffic flow control shown in Figure 6. Sensors along or in the street (for example, induction loops) detect and measure passing vehicles. The sensors feed data about the types of vehicles and their speeds to a local traffic manager whose task it is to obtain an efficient and harmonious flow of traffic. The manager continuously evaluates the received data to find the optimal time settings of the traffic signals as well as the suitable velocity to recommend to the vehicles. This manager also handles requests for intersection priority by special types of vehicles (public transport and heavy trucks).

For a harmonized flow of traffic, control of more than just the traffic signals is necessary; preinformation must be given to the vehicles and drivers approaching the intersection so that they can adapt to the active restrictions in due time. The local traffic manager uses the roadside transponders to distribute adequate data to the passing vehicles. This data should contain information about the distance from the transponder to the intersection, the time until the start and end of the next green period, the cycle time of green period, and the length of queuing vehicles. Then the driver can adjust the vehicle’s speed to pass the intersection during the green period. Furthermore, for a smooth flow of traffic the transponders should also give preinformation about the status of the traffic signals at the next two or three intersections ahead.

An AICC vehicle picking up this transponder information determines a velocity profile that also takes into account minimal fuel consumption and pollutant emissions. The display of the complete velocity profile in the form of the recommended velocity lets drivers accept and fulfill a command (informative mode) or choose to feed the data into the AICC system for automatic realization (automatic mode).

Preceding vehicles also have to be considered and evaluated in combination with the traffic signals ahead. The system accomplishes this by continuous evaluation of the information gained by the distance sensor mounted in the front of the AICC vehicle. Consequently, when approaching a vehicle ahead, it changes the priority of the control objec-
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Figure 7. Field trial for traffic flow harmonization at Hjalmar Branting Street.

Traffic flow harmonization. Harmonizing the flow of traffic has a potentially positive impact on the protection of the environment and the reduction of fuel consumption. The objectives of the harmonization field trial are to explore and estimate the effects on traffic efficiency, fuel consumption, and pollutant emissions when providing AICC vehicles and drivers with preinformation about speed limits (present and future) and the status of traffic signals ahead.

Hjalmar Branting Street is a highway located in the city of Gothenburg. A 3.5-km stretch of the street has speed limits of 50 km/h and 70 km/h, and six signal-controlled intersections, as shown in Figure 7. The timing of the traffic signals are static but fixed to yield a green period when traveling at...
Figure 8. Aspen Track roadside information for active safety.

the appropriate speed. (This speed is not announced and is generally unknown to ordinary drivers.) This street has been equipped with a number of Compose transponders. Each transponder gives information on the speed limit and the status of the traffic signals at the next three intersections, more or less in accordance with that previously described.

AICC SRC-equipped vehicles from Volvo and Saab will be driven in a series of designed runs by ordinary drivers on Hjalmar Branting Street. The following three different driving modes will be investigated:

- **Manual.** With no RTI support, the driver has to manually adjust the speed of the vehicle.
- **Informative.** With information about the speed limit and green period recommended speed, the driver has to manually adjust the speed of the vehicle.
- **Automatic.** With the same information given to the driver as in the informative mode, the AICC system automatically adjusts the speed of the vehicle.

During the test runs variables such as velocity, fuel, and consumption are logged for later analysis of the effects of efficiency, fuel, and pollutant reduction. Based on those results, extrapolations to traffic in larger populations of AICC, SRC-equipped vehicles can be carried out.

Already, this field trial has provided technical experience concerning the SRC link and its advantages and drawbacks in a complex real-traffic environment. One very obvious result in particular is that a real traffic environment demands very robust and reliable SRC systems. More results from the field trial are expected to be available during 1993.

**Aspen Track, roadside information for active safety.**

An SRC link from the roadside to passing vehicles yields the advantage of feeding information into the vehicle system so it can be given to the driver at the correct location and time. This information may change the driver's behavior and, as a consequence, have an impact on the safety not just of the driver but also that of the surrounding traffic and unprotected pedestrians.

East of Gothenburg around Aspen Lake is a track of approximately 35 km of rural and motorway roads, as depicted in Figure 8. Aspen Track has been equipped with transponders transmitting information on speed limits, road curvature, and recommended speeds on sharp bends, warnings of pedestrian crossings, and other relevant information. The field trial explores the effects on driver behavior and safety when using roadside information. The driving behavior of a number of ordinary test drivers using AICC SRC-equipped ve-
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Vehicles from Volvo and Saab when driving on Aspen Track will be studied and logged. The modes of driving are similar to the one used in the traffic flow harmonization experiments.

- **Manual.** With no RTI support, the ordinary driver has to adjust the speed of the vehicle.
- **Informative.** With information about the speed limits, warnings, and so on, the driver has to manually adjust the speed of the vehicle.
- **Assisting.** With the same information, the AICC system automatically realizes the recommended speed.

We executed this field trial at the end of 1992 and expect results from the evaluation in early 1993.

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**References**


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