by Isabel Wilmink & Bart van Arem

COOPERATE AND SURVIVE

INTEGRATED FULL-RANGE SPEED ASSISTANCE

Cooperative road-vehicle systems will help reduce the number of accidents and improve traffic flow efficiency. TNO has developed a tool suite to assess to what extent cooperative systems can fulfil this promise

The IRSA combines the ACC functionality with a cooperative system that looks multiple vehicles ahead. The system is based on GPS, environment sensing and vehicle-to-vehicle communications

In the years to come, it will be increasingly common for intelligent infrastructure and intelligent vehicles to work together and form 'cooperative road-vehicle systems'. This will create new opportunities to improve throughput, safety and the environment. Vehicles and drivers will receive information from the surrounding vehicles or the infrastructure and will be able to anticipate unusual and potentially dangerous situations (such as congestion or roadworks) – or they could simply use the information to avoid receiving speeding tickets!

Drivers control the speed of a vehicle, taking into account local traffic conditions as well as applicable speed limits. However, the local speed limit may not always be clear and sometimes drivers might be late for an appointment and may, perhaps without even realizing it, exceed the speed limit. Such decisions are therefore sensitive to judgment and operational errors.

Many accidents are speed related and partly due to human error. And in cases of congestion, human drivers are typically poor controllers. Therefore, drivers need assistance at higher, as well as lower, speeds.

ADVANCED DRIVER ASSISTANCE

Advanced Driver Assistance (ADA) systems can help drivers to choose an appropriate speed (or keep the vehicle from drifting from a lane, or avoid obstacles, etc). An example of an ADA system that is commercially available is Adaptive Cruise Control (ACC): by extending a 'regular' cruise control system with a radar sensor, the vehicle can maintain a preset speed, but also adapt the speed to a slower predecessor. In addition to sensors on the vehicle, ADA systems can also use wireless communication systems to receive information from roadside systems and other vehicles regarding changes to local speed limits and the speed of downstream traffic. When combined with ACC, this technology is known as CACC – or Cooperative Adaptive Cruise Control.

The real-world pilot of the IRSA system

In 2003, TNO started the SUMMITS program with the objective to develop and demonstrate cooperative systems. In parallel to that, an integrated tool set – the SUMMITS tool suite – was set up for the development, testing and evaluation of such cooperative systems. The SUMMITS tool suite allows developers of ADA systems to assess issues regarding technical functioning, human factors and traffic flow in a consistent way. The Integrated full-Range Speed Assistant (IRSA) was selected as a case to guide and test the development of the tool suite. The results from the SUMMITS program were presented at a symposium on cooperative systems held on 28 March 2007, in Eindhoven, the Netherlands.[1]

THE INTEGRATED FULL-RANGE SPEED ASSISTANT (IRSA)

The IRSA system is a collection of functions to support a driver in maintaining an appropriate speed in a number of selected traffic conditions, such as approaching a traffic jam, cut-in situations, and leaving the head of the queue at a traffic light. In the first two scenarios, the aim of IRSA is to help the driver slow down in a safe and comfortable way; in the third scenario, the aim is to help drivers accelerate in an efficient way, which improves the safety and throughput at traffic lights.

In the development of IRSA, several aspects had to be investigated – i.e. questions that need to be answered. To what extent can cooperative driving achieved through vehicle-to-vehicle and vehicle-to-infrastructure communication contribute to improved traffic and system safety, improved throughput, improved environmental aspects (gas emissions and noise) and improved driver comfort and safety perception? To what extent can it add value to existing ADA functionalities, such as ACC, Stop&Go, Forward Collision Warning, Lane Departure Warning? Also, what implementation issues exist, in the areas of robustness/graceful degradation, stepwise introduction (from 0% to higher-penetration levels), structured design methodologies and expected social benefits under different circumstances?

These questions were considered on three different levels, inlcuding traffic flow level, cluster level and vehicle level, using the various tools in the SUMMITS tool suite.

THE SUMMITS TOOL SUITE

The SUMMITS tool suite consists of different tools that cover specific aspects of cooperative vehicle-infrastructure systems, varying from traffic-flow analysis to assessment of human factors, and from dependable cooperative control architectures to fault-tolerant hardware implementation. These tools include driving simulators and instrumented vehicles, MARS, PreScan and ITS modeler – simulation environments for the design and evaluation of the next generation of intelligent vehicles, suitable for different levels of detail. Another tool available is VEHIL (VEhicle Hardware In the Loop) – TNO's laboratory for testing and development of intelligent vehicle systems with moving bases.

The first step in the development of the IRSA system was the definition of a common mathematical model (the meta-model) by a team with different backgrounds and expertise (covering the various tools), among them traffic and automotive engineers, psychologists and mathematicians. They considered the vehicle, cluster and traffic flow levels and defined the IRSA system in such a way that all 'levels' could work with the same meta-model. So, the same IRSA controller is assessed in the ITS modeler, the driving simulator, or in an experiment on the road (albeit with varying levels of detail in the algorithms).

TRAFFIC SIMULATIONS

The ITS modeler functions as a shell for several commercially available traffic simulation tools. It can overrule the 'normal' vehicle and driver behavior of those models, so that behavior resulting from the use of cooperative systems can be introduced for the equipped vehicles and infrastructures. It simulates traffic on the network level and computes figures on route flows, route travel times, total network journey times and delays, speeds, etc. Safety statistics produced include the number of shockwaves, times-to-collision and time headway intervals. Environmental impacts can be derived as well, including noise and pollutants.

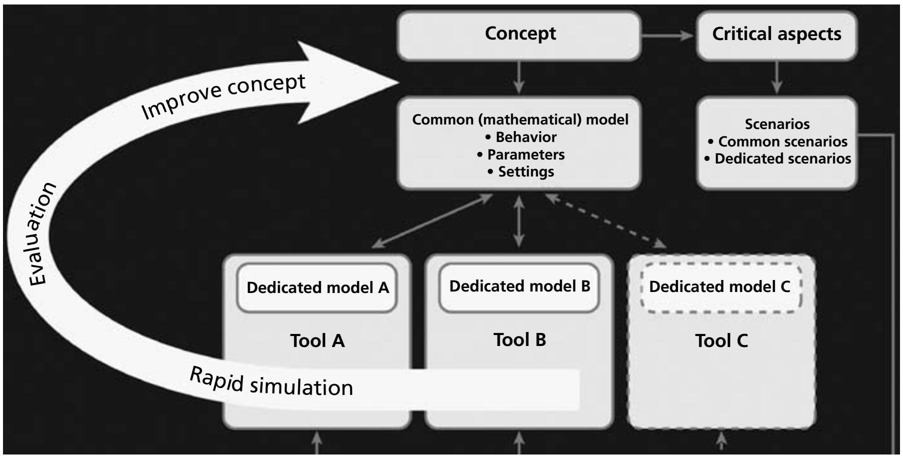

Figure 1: The SUMMITS suite was set up for the development, testing and evaluation of cooperative systems and allows developers to assess technical functioning, human factors and traffic flow issues

IRSA was implemented in the ITS modeler for three different modes (advisory, intervening and controlling). The starting point for the controlling mode was the common mathematical model, which was translated into algorithms suitable for the ITS modeler. Several settings were tested (e.g. for minimal headway and acceleration/deceleration rates). The first results led to an adjustment of the IRSA controller; this was subsequently implemented in the ITS modeler (and the other tools).

"The IRSA system is a collection of functions to support a driver in maintaining an appropriate speed"

For the advisory and intervening modes, the main question to be answered was how the driver is expected to react at the moment he receives the message, and how this depends on the message, the HMI and the traffic conditions. This may be different from the vehicle behavior in the controlling mode of the system. Several possible driver reactions were tested in the simulations.

RESULTS

In all of the scenarios, IRSA contributed to the goals of improving throughput or safety and the environment, but the effects depend on the situation and settings of the system. The main benefit of IRSA is that the distance to the car in front can be maintained in a better way: safer, more comfortable, or with a higher throughput, depending on the settings. The added value of communication is clear when comparing the IRSA CACC versions with just ACC. Settings were selected that ensured safety was never compromised, which meant that in one scenario (approaching a reduced speed limit zone), travel times deteriorated slightly.

Some of the results of the approaching-a-traffic-jam scenario were examined in more detail. In this scenario, the reference

TNO's VEHIL laboratory: with the increasing demand for safer passenger vehicles, the development of Advanced Driver Assistance systems is a major research area within the automotive industry

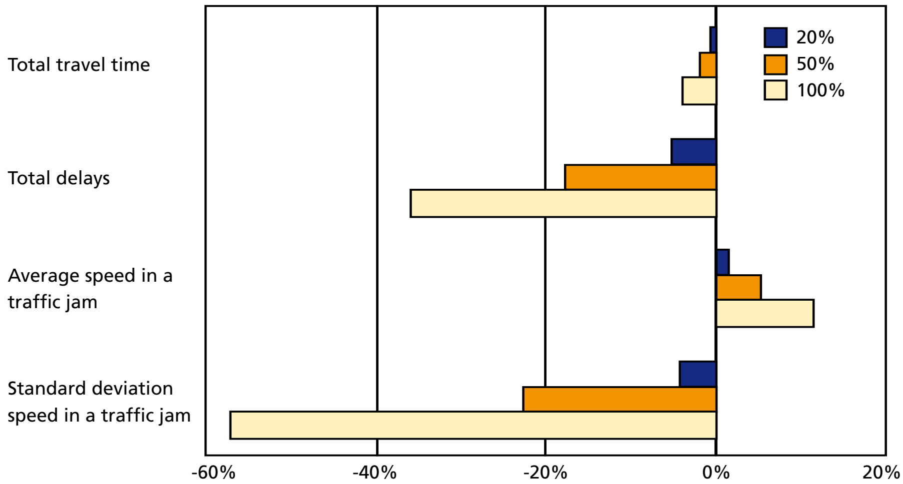

Figure 2: The above shows that travel times and the variation in speed decrease on the whole section (with the average speed increasing slightly)

situation was a three-lane motorway with a lane drop halfway and near-capacity traffic. When vehicles are driving at speeds below 70% of the speed limit, vehicles equipped with IRSA send out warning messages. The system will start braking when the speed is at least 10% higher than the speed of the sending vehicle, with a constant deceleration based on the speed of and distance to the sending vehicle.

IRSA also uses ACC to control its speed automatically, taking into account the positions of the vehicles in front. By using vehicle-to-vehicle communication, more downstream vehicles can be taken into account and combined into a cooperative ACC controller (CACC).

In the advisory mode, the system advises the drivers of these vehicles when to start slowing down and how hard to brake. It was assumed that the driver will brake with the same constant deceleration as in the controlling mode (the difference is that in the advisory mode, the vehicle is not equipped with an ACC or CACC system).

The simulations (for penetration rates of 20, 50 and 100%) showed that IRSA has a positive impact on traffic flow with all versions tested. Vehicles slowed down earlier, having to brake less hard. The lane-changing process at the lane drop appeared to benefit from this (although the IRSA system does not directly influence the lane-changing behavior) and the congestion was reduced, with safety indicators staying at the same level or improving slightly.

Figure 2 shows that the travel times and the variation in speed decrease (with the average speed increasing slightly) when the whole section is looked at. Just before the congested area, the variation in speed actually increases (as the equipped vehicles start braking at different times, depending on the difference in speed between the vehicles in the queue and how far away they are). On the whole, however, traffic appears to be more homogeneous, which is confirmed by a decrease in the variation in accelerations (by up to 40%). From this it can be concluded that in this scenario IRSA contributes to improved traffic safety and lower exhaust emissions. Delays are reduced by more than 30% for all CACC versions and by more than 20% for advisory IRSA.

The second version of IRSA performs the best as the incorporation of information about the speeds of preceding equipped vehicles (at all times) helps to smooth the traffic. The added value of messages from vehicles driving at speeds below 70% of the speed limit is clear for the (less efficient) first version of the controller and for the lower penetration rates of the second. At a penetration rate of 100%, the information from the three predecessors alone is enough to reach the maximum impact.

ASSESSING A SYSTEM

Assessing a cooperative system is not a simple task: in many cases, we are looking at future systems for which the available specifications are often not very detailed. Many variations are possible (such as in respect to the available sensors, the HMI, the settings, and the control/warning algorithms). For advisory systems, the driver reaction has to be approximated and for cooperative systems, the communication has to be modeled – what messages, to whom, with what frequency and spatial/temporal validity, etc?

In the assessment of cooperative systems at the traffic flow level, the ITS modeler enables users to adapt vehicle and driver behavior, so that different algorithms and settings can be tested easily. The changes in traffic patterns can be seen immediately in the traffic model's user interface. The output of completed runs can subsequently be used to assess the effects on traffic flows. Depending on the scenario – and the hypotheses tested – different indicators are used to assess the effects, from aggregated variables such as the average journey time and mean speed to disaggregated results, such as speed profiles. Together, all of these indicators provide the full picture needed to assess cooperative systems, particularly in dense traffic where there will be many interactions between vehicles.

Positive effects were found in the assessment of IRSA and results like these are a first step toward implementation of cooperative systems. Field trials are the next logical step, in which awareness of cooperative systems can be raised and the technical and practical feasibility can be assessed. Simulations such as those discussed in this article can help save time and money in the preparation of these field trials, and can help reduce the uncertainty in the expected impacts. ■

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[1] http://www.tno.nl/content.cfm?&context=overtno&content=nieuwsbericht&laag1=37&laag2=2&item_id=2007-01-31%2016:35:56.0&Taal=2

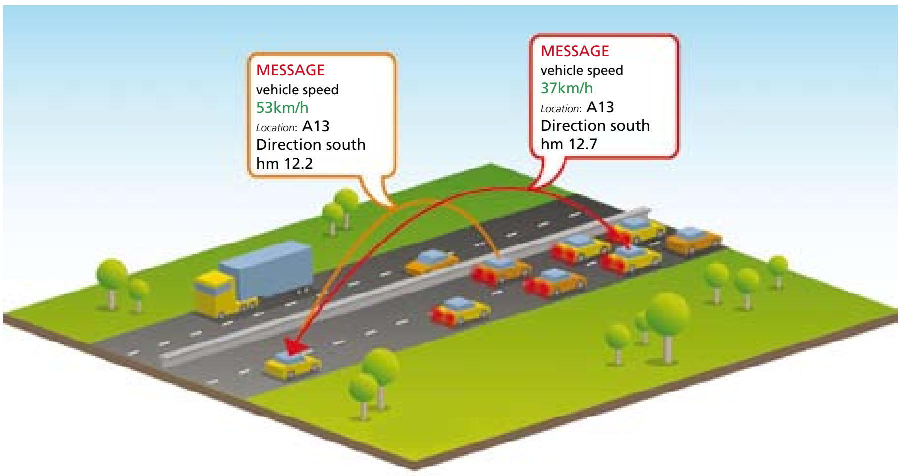

Figure 3: The primary aim in this scenario is to increase traffic safety, so by alerting drivers to slow down for traffic further downstream, a driver will be better prepared for the braking maneuver