Enabling Safety and Mobility through Connectivity

2010-01-2318
Published
10/19/2010

Chris Domin
Ricardo Inc.

ABSTRACT

Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) networks within the Intelligent Transportation System (ITS) lead to safety and mobility improvements in vehicle road traffic. This paper presents case studies that support the realization of the ITS architecture as an evolutionary process, beginning with driver information systems for enhancing feedback to the users, semi-autonomous control systems for improved vehicle system management, and fully autonomous control for improving vehicle cooperation and management. The paper will also demonstrate how the automotive, telecom, and data and service providers are working together to develop new ITS technologies.

INTRODUCTION

A primary goal of ITS is to provide substantial benefits in real world fuel economy, road congestion, and general road safety. ITS has its roots in leveraging leading edge technologies, beginning with driver-focused applications, building towards semi-automatic operations, and ultimately arriving at autonomous operations.

FROM SIMPLE FEEDBACK TO AUTONOMOUS SYSTEMS

A number of passive information systems are available to drivers today. Nowadays it is common for basic driver information systems to provide some kind of vehicle status relative to the environment. For instance, a basic collision warning system can alert the driver if there is an impending rear-end collision or if it detects a pedestrian obstacle. Similarly, a travel information system can alert the driver for upcoming road obstructions. By combining information from the immediate environment with longer-range environment, higher degrees of fuel economy and safety are achieved.

As an example of fuel-economy and safety improvements, Ricardo UK Limited with its academic, business, and ITS committee partners, have developed in-vehicle applications to provide feedback to the driver about fuel-economy and safety conditions. Currently available technologies, such as GPS, cell phone, back-office systems, are used. Two recent programs of note are

• Foot-LITE - A smart electronic co-pilot provides fuel economy information and impending economy-changing situations to the user. A small portable display unit is connected to ITS infrastructure and provides the vehicle driver real-time feedback about actual driving behaviour vs. ideal fuel-efficient behaviour. A web-based service provides historical trends for the driver and allows information sharing with other users.

• Co-Driver - An electronic hazard warning system provides situational awareness of road safety conditions and impending hazards. An in-vehicle unit processes hazard information such as steep grade, sharp curves, obstructions, etc., and provides advanced warning of the potential hazard. Co-Driver also indicates the degree of urgency the hazard presents to the user, for instance, a fallen tree across road versus routine road construction markers. Vehicle passengers can easily enter information back to the system in order to alert other drivers of transient hazards, such as obstacles in the road or accidents.

Applications such as these help the driver make decisions about driving habits and navigation. Reduced fuel costs, reduced CO_2 emissions, and safer driving are direct benefits of these technologies. In addition, even further advances are possible by utilizing semi-autonomous and autonomous technology.

CASE STUDY #1: SEMI-AUTONOMOUS "SENTIENCE"

Fuel efficiency can be improved by integrating topographical and geophysical data with automatic vehicle control subsystems. *Sentience* is a recently completed 2 ½ year collaborative R&D program that was co-funded by innovITS[1]. It was jointly developed with six European partners: Ricardo, innovITS, Jaguar/Land Rover/Ford, Ordnance Survey, Orange, and TRL. The overall achievement of this program is the identification and development of a system to improve the fuel efficiency of vehicles using "electronic horizon" data collected with V2I communications. *Sentience* performs intelligent speed adaptation based on situational awareness.

Sentience is built using a web-based server and mobile client application. The server environment includes the telecommunications infrastructure, GPS satellites, weather data, ITS traffic data, historical traffic trend data, and the *Sentience* application web-server. The server translates data from the environment, categorizes them, and communicates them to the client using V2I.

The *Sentience* client application resides in a smart-phone mobile device that is part of the *Sentience* on-board system. The *Sentience* on-board system includes the GPS receiver, the mobile device (cell phone), and real-time supervisory controller unit (SCU). The vehicle interface software and supervisory control algorithms execute on the SCU. The SCU software communicates directly with the acceleration/braking subsystem electronics and over dedicated Ethernet with the client software on the mobile. The SCU software is responsible for optimization of regenerative-braking, air-condition boosting, and EV mode operations.

The team selected a Ford Hybrid Escape as the target vehicle for the prototype system. A hybrid vehicle presents several opportunities not available on conventional vehicles. The Ford Escape is a full hybrid vehicle and can operate in several modes: full electric, conventional combustion, and mixed (parallel) mode. It also utilizes regenerative braking.

SENTIENCE REQUIREMENTS AND SIMULATION

Phase one of the project focused on simulation and requirements specification. Ordnance Survey, Orange, and TRL focused on defining the vehicle routes and supporting data. Ricardo focused on simulation, control strategies, and prototype architecture. The team created and validated a vehicle model to assess baseline vehicle performance.

The primary opportunities found for energy savings are regenerative braking, EV usage during acceleration, and air-conditioning usage. Through measurement and analysis, the team found when it was best to run the electrical motor and when it was best to charge the battery based on road conditions and vehicle characteristics. This analysis allowed selection of optimum tradeoff points between electrical drive and conventional drive for vehicle speed and wheel torque.

U.S. EPA cycles were used to validate the model. Subsequent simulations included different route profiles and varying drive conditions, such as level or hilly routes, constant or varying speeds, with/without air-conditioning, head/tail wind, etc.

- Flat 12.4 mi route, 60mph
- 12.4 mi route (0.6mi flat, 3.7 mi uphill, 7.5 mi downhill, 0.6 mi flat), 60mph
- Flat 12.4 mi route, 30mph, air-conditioning turned on
- Flat 12.4 mi route, variable speed (multiple discrete target speeds) with average of 30mph
- 12.4 mi route (0.6 mi flat, 11.2 mi of repeated alternate 0.6 mi uphill, 0.6 mi downhill gradients, 0.6 mi flat to end), 30mph

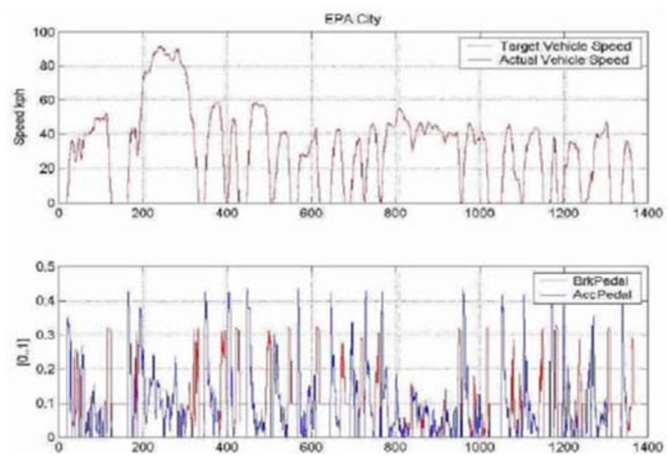

Figure 1. EPA Test Cycle

The on-board *Sentience* architecture incorporates V2I communications to access electronic horizon data, such as topographical, geographical, and traffic data, from the *Sentience* web server. The team performed a sensitivity analysis of the look-ahead algorithm to characterize how deep the queue of traffic/map data must be in order to maximize efficiency of the algorithms and to account for temporary interruptions of service. As a result, the on-board *Sentience*

[1, 2] InnovITS is the UK Centre of Excellence for sustainable mobility and intelligent transport systems. See http://www.innovITS.co.uk Simulink® is a registered trademark of The MathWorks™.

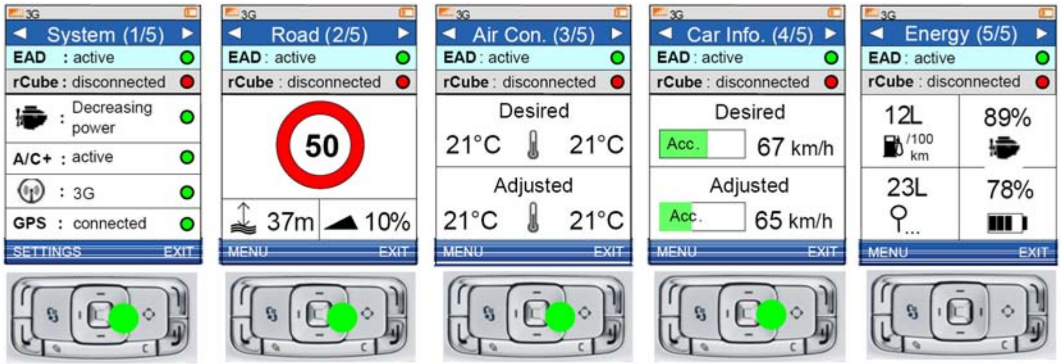

Figure 2. Sentience HMI sample

system views an electronic horizon of up to 3 miles to calculate optimum acceleration/regeneration potential.

A key requirement of the on-board system was a safe implementation with minimal cost. For this reason, a Ricardo rapid prototyping system was selected for the SCU. The SCU intercepts and overrides controls for cruise control and air conditioning. It communicates with the powertrain controller for hybrid, engine, and safety functions. A safety cut-off function for the enhanced acceleration and deceleration was identified as being required during the preliminary safety analysis.

The team, with input from Ford, assessed vehicle systems for suitability, and concluded that a small amount of additional hardware was required to ensure the vehicle system did not raise faults against the cruise control or air conditioning switchgear.

SENTIENCE DEVELOPMENT AND ASSESSMENT

Phase two of the project focused on development, integration, and assessment.

A Nokia N95 cellular phone served as the mobile communications device and human-machine interface (HMI) for the on-board system. For convenience, an external GPS was connected to the phone to provide location information. Ricardo and Orange defined and implemented a telecommunications protocol for communication between the phone and the SCU. Ordnance Survey data provided the historical traffic data. For future use, the *Sentience* architecture supports the of real-time traffic data from ITS infrastructure sources. *Sentience* focuses on three main areas of system operation to optimize energy storage and transfers: engine loading, air-conditioning, and acceleration/braking. See discussions on OEL, EAC, and EAD below.

The *Sentience* HMI on the mobile device displays road information as well as *Sentience* status information, e.g,

- Road speed limit, height and gradient
- Enhanced Air-Conditioning level desired and adjusted temperature set-point
- Enhanced Acceleration/ Deceleration level desired and adjusted vehicle speed
- Energy status information such as battery state of charge

Sentience detects when the vehicle is approaching significant changes in driving conditions due to traffic or geography, and displays pop-ups on the HMI. *A* configuration screen allows the user to select the desired features. The user can selectively enable and disable both pop-ups and audio messages by feature.

Sentience subsystem components are discretely installed in the vehicle under the passenger seat and in the dash. *Sentience* components include a custom harness, a modified A/C control unit, a custom cruise-control unit, the SCU, a wireless router & GPS receiver, and a CAN data logger device.

Sentience Optimized Engine Loading (OEL) executes on the SCU and optimizes the efficiency of the hybrid powertrain through intelligent management of electric, mixed and combustion modes of operation. The OEL algorithm communicates to the powertrain controller via the CAN network and provides supervisory control. Advanced knowledge of opportunities to recharge the battery system allows more flexibility in EV use, e.g., the battery state of charge limits are adjusted with the vehicle operation utilizing these limits. Ricardo developed supervisory control strategies in Simulink® for execution on the *Sentience* SCU. With the current OEL strategies, a 4-9% improvement in fuel consumption is realized.

Sentience Enhanced Air Conditioning (EAC) executes on the SCU and optimizes the A/C operation in order to reduce the CO_2 emissions from the vehicle. Because the combustion engine drives the A/C compressor directly, a specialized strategy was developed to keep the passengers comfortable during extended vehicle stops. EAC overrides the A/C switchgear signals and "pre-cools" the interior 1 or 2 degrees cooler whenever extended stops are predicted. By minimizing the amount of occurrences when the engine runs exclusively for cooling the vehicle interior, a result of a 2-10% improvement in fuel consumption is realized.

Sentience Enhanced Acceleration / Deceleration (EAD) is a form of adaptive cruise control, where vehicle speed as well as acceleration and deceleration profiles are controlled with the knowledge of future traffic and geography features. EAD augments the existing cruise control strategy. *Sentience* automatically controls the speed at a more optimal rate than might be expected through normal driving, allowing potentially significant savings in fuel. Speed set points are a combination of fixed-feature speed limits and probabilistic-feature speed limits. Fixed-features include actual speed limits, bends, roundabouts, speed bumps and stop signs. Probabilistic features include traffic lights, junctions, traffic conditions and pedestrian crossings. EAD slows or accelerates the vehicle at an optimum rate to match legal or safe speeds. The driver can manually override EAD at any time for safety or convenience. Depending on traffic conditions, EAD may have an impact on journey time; the driver therefore could make an informed decision as to whether the trade-off with increased comfort and fuel efficiency is acceptable on that occasion.

Figure 3. OEL Hilly Terrain Optimization

SENTIENCE VALIDATION AND CONCLUSIONS

1. Three new control systems were added to those on a production hybrid vehicle. OEL for enhanced hybrid system efficiency is useful under any mode of operation. EAC can be used whenever air conditioning is turned on. EAD can be used whenever cruise control is active.

2. Track and road testing results indicated significant savings. Improvements in fuel consumption on the order of 5%-10% can be obtained for a low implementation cost.

◦ With OEL, simulations predicted savings of 4-9%; Initial track test measurements show savings of approximately 2%, with speculation of higher percentage savings on specific routes. Further analysis and testing continues.

◦ With EAC, dynamometer-testing using an NEDC cycle with simulated sunlight loading has been performed. Over 9% improvement in fuel consumption was seen on an NEDC cycle under moderate mild summer weather conditions.

◦ With EAD, initial measurements show an average saving ranging between 5% and 24%, with an average of 12% during track testing. Scaling this data to average vehicle usage on real roads gives a total estimated fuel saving of nearly 14%. Initial real world road tests have already shown a fuel savings of over 5%.

3. Implementation costs for *Sentience* using a production system is not restrictive. Typical 3G mobile phones come with GPS capabilities and can be acquired for low cost. Memory and CPU requirements for OEL, EAC, and EAD functions do not prevent those features from being co-resident with software in production ECUs. Suitable sources of traffic data are required, but these traffic data can be easily supported by future ITS infrastructure.

CASE STUDY #2: AUTONOMOUS "SARTRE"

Both fuel efficiency and safety are improved by integrating V2V communications and automatic vehicle control subsystems. *SARTRE* is a Ricardo-led program that shares situational awareness data between vehicles using V2I and V2V communications, thus enabling autonomous vehicle coordination and the creation of "road trains".

The *SARTRE* project began in September 2009 and is scheduled to complete in August 2012. It is being jointly developed with seven European partners in the UK, Sweden, Spain, and Germany: Ricardo, IDIADA Automotive Technology, Institute for Automotive Engineering (ika) of RWTH Aachen University, SP Sveriges Tekniska Forskningsinstitut, TECNALIA Robotiker, Volvo Car Company, and Volvo Technology. The concept behind *SARTRE* is that vehicle platoons improve fuel consumption, increase safety, and reduce congestion on freeways.

Since human driver errors contribute to well over 85% of road fatalities, it is expected that safety will improve dramatically by using autonomous control to remove distractions and errors in judgment. Because autonomous systems can process data much more quickly than a human can, congestion can be reduced automatically by optimizing gaps between vehicles, minimizing traffic dynamics and delaying traffic collapse. Fuel economy can be improved by

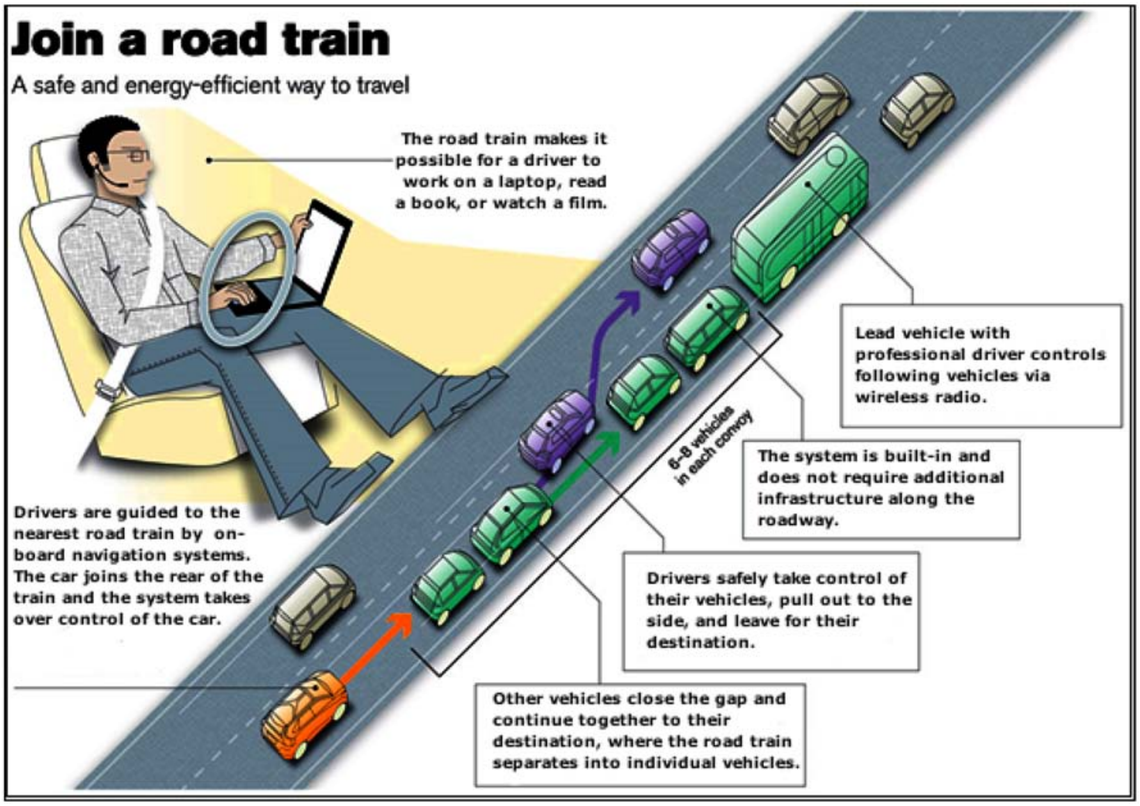

Figure 4. The SARTRE concept

reducing aerodynamic drag, due to drafting in each vehicle's slipstream.

Each road train will consist of up to eight vehicles. Each road train or platoon has a lead vehicle that drives exactly as normal, with human control over the various functions. This lead vehicle is controlled by an experienced driver who is familiar with the route. For instance, the lead may be taken by a taxi, a bus or a truck. A driver approaching the convoy requests entry into the convoy using a human-machine interface. The convoy accepts the vehicle and the vehicle automatically enters the convoy, after which it is completely under autonomous control. A driver approaching his destination leaves the convoy by exiting off to the side and then continues on his own to his destination under his own control. The other vehicles in the road train automatically close the gap and continue on their way until the convoy splits up.

The advantage of such road trains is that all the other drivers in the convoy have time to perform other business while on the road, e.g., talking on the phone, eating, working on a computer, etc. The road trains increase safety and reduce environmental impact thanks to lower fuel consumption compared with cars being driven individually. The reason is that the cars in the train are close to each other, exploiting the resultant lower air drag. Simulation results show the energy saving to be in the region of 20 %: Road capacity is utilized more efficiently by minimizing distance between vehicles.

Researchers see road trains primarily as a major benefit to commuters who cover long distances by motorway every day, but they will also be of potential benefit to trucks, buses, coaches, vans and other commercial vehicle types. As the participants meet, each vehicle's navigation system is used to join the convoy, after which the autonomous driving program then takes over. As the road train approaches its final destination, the various participants can each disconnect from the convoy and continue to drive as usual to their individual destinations.

SARTRE REQUIREMENTS AND SIMULATION

Phase one of the project considered scenarios and constraints during interaction with other road users. A use-case analysis was performed with an emphasis on the human factors. Modeling of the use cases focused on creating a combination of vehicle and traffic specific models, taking into consideration all interchanges occurring between driver, vehicle and other traffic.

An important constraint for *SARTRE* is that the architecture and implementation has to be feasible and use available production components and subsystems. So the team performed additional analysis to understand business

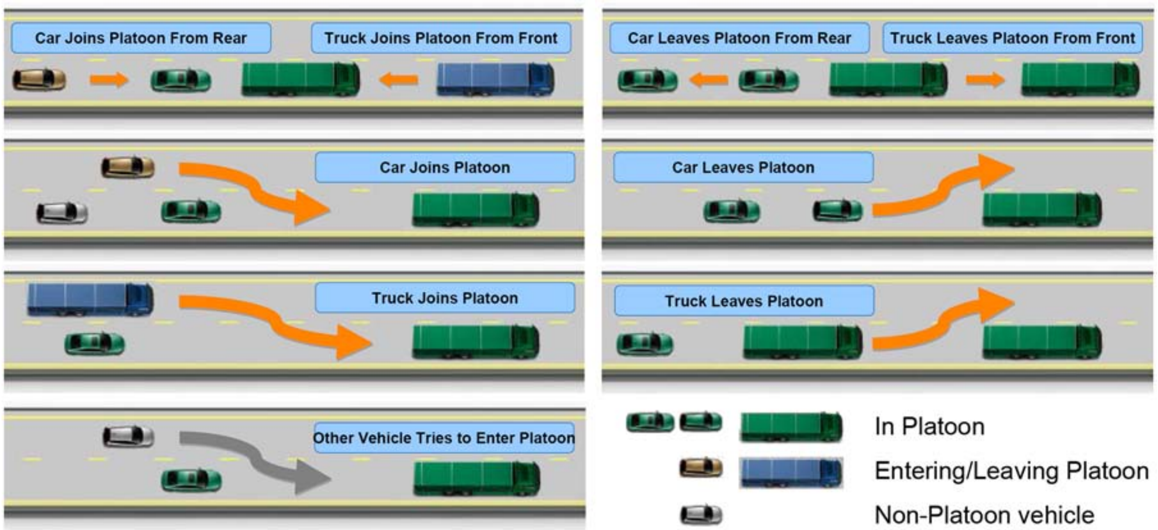

Figure 5. SARTRE Platoon Use-Cases

requirements, usability, risk, and safety, as well as the system itself. As the concept solutions were balanced against available technology, they were rationalized against draft ISO/DIS 26262 using InnovITS[2] Framework Architecture and Classification for ITS (FACITS) process.

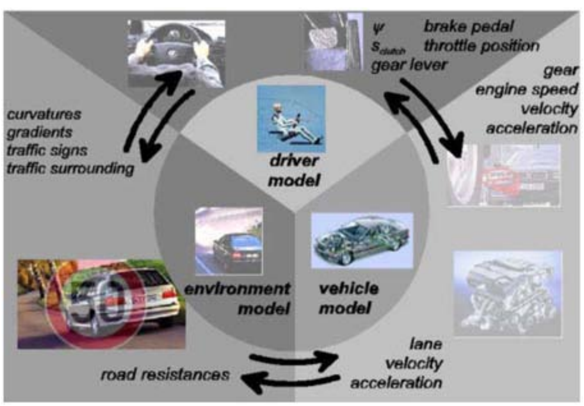

Figure 6. Modeling Process

Use-cases (see Figure 5) needed to take into account a significant number of factors, including, performance/failure of vehicles, braking/acceleration/turning procedures, other vehicles, platoon size, and gap length, and human behaviors, among others. Example use cases are:

• authorized car/truck enters platoon from rear or joins middle of platoon

• unauthorized other car/truck enters platoon or leaves platoon from middle

• authorized car/truck leaves from rear or middle

• authorized leader joins or leaves from front

After all the primary modeling, analysis, and concept generation were complete, the team focused on concept implementation.

SARTRE CONCEPT IMPLEMENTATION

Phase two of the project involves concept selection and implementation. Since intellectual property is being developed by partners to support the implementation of *SARTRE*, only a general discussion of the architecture is given here. Each vehicle is equipped with a dedicated short-range communications (DSRC) radio, an active safety control module, short-range radar, vision systems, active cruise control system, actuators, and supervisory control unit (SCU). DSRC is used to communicate platoon information among all vehicles in the platoon. Once in the platoon, V2V communications, V2I communications, and other active subsystems in each vehicle support autonomous behavior.

To date, the project partners have reached agreements on the factors necessary to proceed with implementation and the concept implementation is underway. Transport behaviour modelling and platoon strategies continue in parallel with human behaviour studies and safety studies. Development of lead vehicles and following vehicles has started. Track studies will soon be performed with the *SARTRE* road-train using three cars and two trucks.

Some of the areas for continued research and refinement are in the areas of

---

[1, 2] InnovITS is the UK Centre of Excellence for sustainable mobility and intelligent transport systems. See http://www.innovITS.co.uk Simulink® is a registered trademark of The MathWorks™.

• Number of vehicles in a *SARTRE* platoon and the mix of vehicles (cars/trucks)

• Specification and architecture updates.

• Safety requirements and analysis

• Updates to V2V Communications (DSRC)

• Inputs regarding V2I findings to infrastructure organizations

• Sensor Fusion Systems

• Actuator Systems

• Human Machine Interfaces

• Autonomous Control System

• Platoon Management System

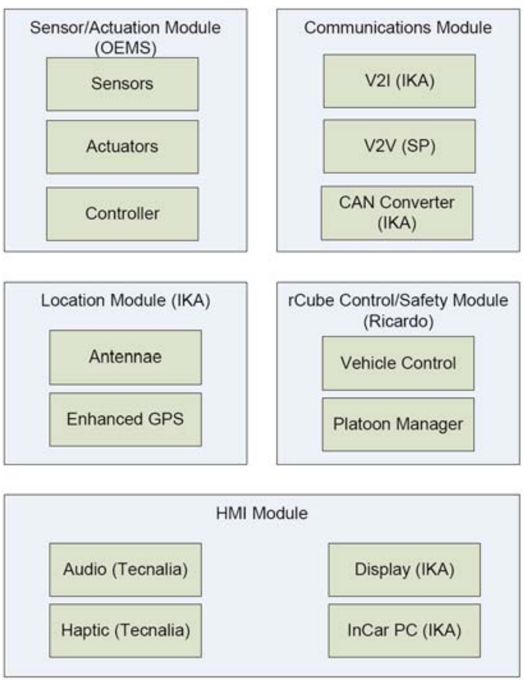

Figure 7. SARTRE Concept Architecture

VALIDATION AND ASSESSMENTS

At the time of the writing of this paper, validation of the systems has not been completed. The plan is to validate the on-vehicle systems, the remote systems, end-to end systems, and fuel consumption claims. Once validation is completed, results of studies will be made available that include assessments of the commercial viability of *SARTRE*, the net impact on infrastructure and vehicles, and potential policy impacts.

SUMMARY/CONCLUSIONS

V2V and V2I communications are changing the ways that people interact with their vehicles. Driver assistance systems are making way for semiautonomous mobility improvements in fuel economy and safety. Future automotive systems will leverage V2I and V2V in order to allow drivers to select semiautonomous and autonomous behaviors, with net gains in safety and mobility. Partnerships between science researchers, policy makers, academia, infrastructure manufacturers, and automotive manufacturers will change the landscape of automotive transportation to a more efficient and safer experience for drivers and passengers.

THE PARTNERSHIPS

The *Sentience* program included each of the following organizations.

Organization	Organization Overview	Role
Ricardo	Automotive Engineering Consultants with expertise in Control Systems, Vehicle Systems, and ITS	• Project Management • Rapid Prototyping Electonics • Vehicle control algorithms
innovITS	UK Dept of Business Enterprise Reform (formerly DTI)	• Promotes UK Telematics/ITS • Funding/Coordination • Program goals
Jaguar/LandRover/ Ford	Prestige UK Vehicle OEM	• Base Hybrid Vehicle • Vehicle Data and Interfaces
Ordnance Survey	UK mapping organization	• Enhanced map data • Traffic congestion data
Orange	Telecoms company	• Telecoms engineering expertise and equipment
TRL	Transport Research and testing Lab	• Vehicle system testing • Test facilities

The *SARTE* program included each of the following organizations.

Organization	Organization Overview	Role
Ricardo (UK)	High value engineering services to the automotive, ITS and clean energy communities	• Coordinator and Management WP leader • Safety Analysis • Platoon Management & Autonomous Control
IDIADA Automotive Technology (Spain)	World-leading company for automotive testing and demonstration	• Validation/Assessment work package leader • Test lead • Road trial lead
Institute for Automotive Engineering (ika) of RWTH Aachen University (Germany)	Leading university in automotive technology	• Concept definition WP leader • Modelling lead • Back office and organisation assistant
SP Sveriges Tekniska Forskningsinstitut (Sweden)	Research institute experienced in automotive safety and communication	• Dissemination WP leader • Use case lead • V2V communications
TECNALIA Robotiker (Spain)	Expert technology centre specialising in ICT	• Human factors assessment • HMI design and implementation
Volvo Car Corporation (Sweden)	Major passengar car OEM	• Implementation WP leader • Following vehicle lead • Following vehicle (car) sensor fusion
Volvo Technology (Sweden)	Major trucks, buses and construction equipment OEM	• Lead vehicle lead • Lead/following vehicle (truck) sensor fusion

CONTACT INFORMATION

Chris Domin
Intelligent & Autonomous Systems
Ricardo, Inc.
40000 Ricardo Drive
Van Buren Twp., MI 48111 USA
Phone: (734) 394-4155
Fax: (734) 397-6677
chris.domin@ricardo.com

ACKNOWLEDGMENTS

Ricardo, Inc. and Ricardo UK Limited would like to thank its partners for support of Foot-LITE, Co-Driver, *Sentience*, and *SARTRE* programs. Chris Domin would like to thank Tom Robinson and Jonathon Hunt from the UK facility for their support while writing this paper.

DEFINITIONS/ABBREVIATIONS

A/C
Air-conditioning unit

CPU
Central Processing Unit, a micro controller

DSRC
Digital Short Range Communications

EAC
Enhanced air conditioning

EAD
Enhanced acceleration/deceleration

ECU
Embedded Control Unit

EV
Electric Vehicle

HMI
Human-machine interface or display

ITS
Intelligent transportation systems

OEL
Optimised engine loading

SARTRE
EU Program: Safe Road Trains for the Environment

SCU
Supervisory control unit

Sentience
EU Program: Using Electronic Horizon Data to Improve Vehicle Efficiency

V2V
Vehicle to vehicle

V2I
Vehicle to infrastructure

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

ISSN 0148-7191

doi:10.4271/2010-01-2318