

# Technical feasibility of safety related driving assistance systems

Meng Lu<sup>1</sup>, Kees Wevers<sup>2</sup>, Evangelos Bekiaris<sup>3</sup>

---

1. Radboud University Nijmegen, The Netherlands. Email <m.lu@fm.ru.nl>

2. NAVTEQ, The Netherlands. Email <kees.wevers@navteq.com>

3. Hellenic Institute of Transport, Greece. Email <abek@certh.gr>

---

## ABSTRACT

This paper explores the technical feasibility of five functions of driving assistance systems to contribute to road traffic safety, to reach stated EU road traffic safety targets. Enabling technologies, their maturity level and development path, with a view on possible large-scale implementation, are addressed. State-of-the-art and potential of enabling technologies like positioning, radar, laser, vision and communication are analysed from a technical perspective, and possible obstacles for large-scale dedicated driving assistance systems implementation for road traffic safety are discussed.

**KEYWORDS:** driving assistance systems, safety, sensor technologies, communication, autonomous systems, co-operative systems

## INTRODUCTION

Road traffic accidents are perceived as one of the major societal problems in the world. [Peden 2004]. Traffic is the result of the interaction between humans, vehicles and road infrastructure. In this process the human is a key element, but also the weakest link. Nearly all traffic accidents are due to human error. Measures to counteract traffic accidents can be classified as: (1) change of human behaviour, (2) physical road infrastructure related measures, and (3) vehicle related measures.

Change of behaviour is promoted by enforcement, information, education and driving instruction, and is largely in the domain of active safety. Related measures are dependent of government initiated action, and their effects are often not lasting. Physical road infrastructure related measures can largely improve traffic safety. However, the large-scale, long-term and costly implementation is insufficient to meet the ambitious EU policy targets for 2010: 50% reduction of accidents. Therefore, vehicle-related safety measures are required. In this category a distinction is made between *passive safety* measures (that aim to protect occupants and pedestrians from injuries caused by a crash), and *active safety* measures (that aim to preventing a crash and minimise the effect of a crash). Passive components contain car structure and restraint systems, e.g. head restraint, seatbelts, front/side airbags, tensioners, clamping mechanism and rollover protection. Elements of active components are *quality of tyres*, *hydraulic brake systems* (i.e. drum brakes, disc brakes, brake boosters), *electronic brake systems* (i.e. anti-lock braking system (ABS), traction control system, brake assist, wheel speed sensors), *stability management systems* (i.e. electronic stability program (ESP), active rollover protection, ESP II with steering intervention and driving dynamic sensors) and so-called *driving assistance systems* (which is also called ADAS - advanced driver assistance systems). ICT (Information and Communication Technology) based driving assistance systems not only help to avoid crash in critical situations, but also assist the drivers in their driving task continuously, in addition have the function to increase comfort and efficiency. The table (see appendix) provides an overview of the applications of safety related driving assistance systems. The development of these systems is progressing, and several applications come closer to possible high volume introduction.

The paper focuses on five safety related functions of driving assistance systems: navigation, speed assistance, collision avoidance, intersection support and lane keeping, which were identified in previous research as potential substitutes for infrastructure related measures [Lu 2003]. In the following sections the technical feasibility of these system applications is analysed in terms of the state-of-the-art of their core technologies (positioning, radar, laser, vision and communication), and both as autonomous and cooperative systems.

## NAVIGATION SYSTEM

The navigation system is a state-of-the-art system, which comes in many different variants, and with user interfaces of different levels of sophistication. It rapidly gains popularity, even for the average driver, as it does not only provide route guidance, but also dynamic traffic information, best route alternative, and estimated time of arrival. Vehicle positioning (inertial sensors, GPS and map matching), route calculation (map database) and route guidance are the main system components. Several of the safe road design requirements to enhance traffic safety could also be addressed by the navigation system with minimal adaptations [Lu 2003]. These are: (1) minimise part of journey on relatively unsafe roads, (2) make journeys as short as possible, (3) let shortest and safest route coincide, (4) avoid search behaviour, and (5) make road categories recognisable.

By nature a navigation system implements requirement 4. Requirements 1, 2 and 3 are fairly related, and in a sense already implemented in a navigation system, to the extent that the outcome is still dependent on the route selection choice that the user has made. The available options for this choice generally include *fastest route*, *shortest distance*, *main roads* (as much as possible), and *avoid main roads* (as much as possible). A navigation system in principle creates the shortest (or fastest) route (requirement 2) in balance with the chosen route selection criterion. The higher the level of the road, the better the separation of different kinds of traffic generally will be, and therefore the safer the route (requirements 1 and 3). The option *main roads* therefore likely provide the best balance between the requirements 1, 2 and 3. The result is dependent on the choices that the map database provider has made with respect to the categorisation of roads, and on the route calculation choices that are made in the software of the navigation system. As an example, the setting shortest route does not always provide the real shortest route, but a smart shortest route, still taking into account some principle of preference of higher level roads and avoidance of residential areas. In view of improving safety, some harmonisation of road categorisation in the map database and of route selection criteria for navigation systems might be considered. Input from public authorities for this is desired. Requirement 5 is very much related to the concept of self-explaining roads. Of course, a navigation system could in principle inform the driver about the type of road he/she is driving on, to induce the right driving behaviour, and in particular the right speed. However, a speed assistance system would in a much better and less intrusive way inform the driver of the expected driving behaviour.

It should be noted that the navigation system also provides a platform for the provision of road traffic information, currently mainly provided as TMC (Traffic Message Channel) messages over RDS (Radio Data System), a data channel in the FM sideband. An example of safety related traffic information is the provision of the precise location of the tail of a traffic queue, which will be possible based on the recently developed TMC Forum Specification for Precise Location Referencing [TMC Forum 2004].

Several applications of driving assistance systems could benefit from map and position data (the map database and vehicle positioning as additional sensor). Examples are curve warning (to provide curvature information for an oncoming curve), and adaptive cruise control (to notice that a tracked vehicle is temporarily lost due to an oncoming curve). A key concept is the ADAS Horizon, which provides an extract of the map database ahead of the vehicle. In the ADASIS Forum and the EU funded MAPS&ADAS project an ADAS Interface Specification is developed [MAPS&ADAS Consortium 2005], to define the related concepts, and to standardise the data streams. An ADAS Horizon Provider (AHP) extracts map data and vehicle position, and provides these data continuously via the vehicle bus system to various applications. On the application of driving assistance systems side, an ADAS Horizon Reconstructor takes the required information from the data stream, and prepares these for the application. The AHP can be incorporated in the navigation system, that already includes map data and vehicle positioning, but alternatively the map data and vehicle positioning can be made a separate unit (the so-called map server), that serves both the navigation system and the AHP.

## SPEED ASSISTANCE

Inappropriate or excessive speed is a crucial risk factor for crash involvement [Peden 2004], especially in the urban environment and on single carriageway extra-urban roads. Therefore one of the key practical and operational control parameters of active safety is speed. Driving assistance system provides technologies to address the issue of speeding, and to promote better (or even complete) conformance with speed limits than other measures like police enforcement, education and improved layout of physical infrastructure.

Although infrastructure based speed assistance is possible, it is generally accepted that future systems will be map-based. In an infrastructure based system the (rough) position of the car and the information regarding the speed limit may be obtained from short-range communication beacons or transponder tags which may be installed at speed limit changes (in general at speed signs along the road). High infrastructure installation and maintenance costs seem to be prohibitive, while on the other hand the increase of driving assistance system components in the car favours the in-vehicle integration of a map-based system.

Map-based speed assistance uses vehicle positioning (GPS, inertial sensors, map matching), determination of the local speed limit (from map database information), comparison of the actual vehicle speed with the local speed limit, and information or warning, or vehicle control. Vehicle positioning and a digital map database are likely to be common components in every car in the future, and are already today standard components of the navigation system. Comparison with the actual vehicle speed is standard technology, as is information or warning through an HMI (Human Machine Interface), or vehicle control (overrideable or non-overrideable).

### System Design Options

Speed assistance systems may be designed in several different ways. An important element is the feedback model that is chosen, for which in general four different levels are distinguished: information (visual or acoustic), warning (acoustic or haptic), overrideable control (haptic throttle) or full control (fuel supply control, gear change and/or braking). Another determinant is the mode of operation, which can be voluntary (on/off switch) or mandatory (autonomous, as soon as the engine is switched on). In recent years many pilots have been carried out in different countries (e.g. Sweden, the UK, France, The Netherlands and Australia), in which various system set-ups have been tested and demonstrated, and also user response and acceptance have been investigated. In these projects the technical feasibility of different speed assistance approaches has been amply demonstrated. Lu [2003] has suggested introducing a sophisticated flexible system layout that differentiates according to road type and traffic safety requirements:

- mandatory full control on roads and crossings with mixed traffic
- mandatory overrideable control (haptic throttle) on single carriageway roads with separation of traffic categories
- voluntary warning on dual carriageway roads specifically designed for motor vehicles

The rationale for this differentiation is based on accident data, the focus of proposed infrastructure measures for traffic safety, and driver acceptance. Motorways are relatively safe, and not so much considered in the infrastructure redesign programmes, as they already largely comply with proposed standards. Most accidents happen in urban areas and on single carriageway extra-urban roads. Infrastructure measures have a strong focus on speed control in these areas. On the other hand, limitation of the freedom of the driver to be in full control of his car is likely to be most strongly felt in the motorway environment.

## Prerequisites for Speed Assistance

A Speed Assistance system needs reliable determination of the vehicle position in the map, and up-to-date speed limit information in the map database. Vehicle positioning as implemented in current navigation systems is very accurate. Only occasionally an error may occur, and for a very short period of time. In such cases the positioning unit generally knows the uncertainty in the vehicle position, and a warning to the driver may be issued by the speed assistance system that reliable speed limit information is not available. The future introduction of the European Galileo satellite positioning system, which will include integrity information, and local augmentation systems to fill local gaps in satellite reception, will further improve future positioning capabilities.

The issue of the availability and reliability of speed limits in digital maps was addressed by the eSafety Working Group on Road Safety [EC 2003]. It is argued that market forces currently push for extension of trip and travel related content of digital map databases, and not so much for inclusion of safety relevant road network data, amongst which speed limits. The conclusion is that due to commercial constraints a European road safety (ADAS) map database is not likely to appear on the market as a sufficiently low-cost product which would enable large-scale take-up of safety applications.

It is questionable if this view is correct. Inclusion of new content in commercial map databases indeed is dependent on market forces. If car manufacturers would in the coming years increasingly offer safety related driving assistance system applications as an option in their car models, this might be a driving force for such inclusion. However, if the public indeed is not willing to pay additionally for such options, in analogy with the experiences with traffic information services [EC 2003] and emergency call applications, then car makers may be reluctant to offer such applications, and not much will happen. But market forces might be steered significantly if speed assistance would be gradually implemented as a mandatory system, as indicated above, according to a European roll-out plan, in new as well as in existing cars. A further conclusion of [EC 2003] is that a European road map database containing additional agreed attributes for driver support and advisory purposes should be produced, maintained and certified under the responsibility of a public-private partnership and made available at acceptable prices for end users (possibly free of charge).

To enable up-to-date speed limits in digital map databases for in-vehicle applications, two prerequisites need to be fulfilled. In the first place the responsible authorities need to organise the legal speed limit information for their roads in a timely and accessible way, and provide this information to digital map database suppliers on a continuous basis. This should enable the provision of certified speed limit data, as is proposed in [EC 2003]. However, an enormous effort is needed here. In general different authorities within a country are responsible for different parts of the road network. Current systems for recording implemented traffic regulations, including speed signs, come in many different variants, are often inaccessible, and sometimes even non-existent. A harmonised implementation of solutions to this problem should be organised at a European level, including solutions for storage and maintenance of road attribute data at authorities, and standardisation of exchange mechanisms. Some of the issues involved are studied in the French-German funded SafeMAP project [SafeMAP Consortium 2003], and in the EU funded projects SpeedAlert [SpeedAlert Consortium 2003] and MAPS&ADAS [MAPS&ADAS Consortium 2005]. Secondly, incremental map data updates with respect to speed limits need to be supplied to the vehicle in a timely manner, and integrated into the map database in the vehicle. This needs mechanisms for incremental updating, which have been explored in the EU funded ActMAP project [ActMAP Consortium 2004], and a suitable data versioning and transfer mechanism to get the right updates in every vehicle.

Introduction of speed assistance by statutory regulation (including the aforementioned differentiation) as an enforcement mechanism, while maintaining the legal liability to obey the posted speed traffic signs, may adequately address the liability issue, and allow speed assistance to be already used if speed limit data in digital maps is not yet complete and up-to-date.

## Further Perspectives

Going one step beyond what is generally discussed, speed assistance could also be used to regulate speed at the approach of intersections, including a slow-down to an adequate speed, and a full stop at a stop sign or a red traffic light. In the latter case the traffic light system needs to be equipped with a short-range communication beacon that transmits its state, and the system in the vehicle with a corresponding receiver, and processing capability.

Compared to physical infrastructure measures, speed assistance has some clear advantages. It has more extensive and homogeneous effects on speed and thereby on traffic safety. It also largely avoids negative effects in terms of land use, emissions and fuel consumption. Moreover, dynamisation of speed assistance provides a plausible perspective for mitigating the congestion problem.

It has been shown by simulation studies that dynamic speed limits could help to prevent, mitigate or eliminate traffic jams and shock waves, by adequate control of speed, density and flow [Hegyi 2004]. Congestion can be dissipated by raising the outflow [Kates 2003], by limiting the inflow to a traffic jam or shock wave [Chien 1997, Lenz 2001], or by homogenising the general traffic flow [Alessandri 1999, Smulders 1996]. All studies are based on the use of variable speed limit signs and static speed assistance [Sentinella 1996, Wilkie 1997]. However, the speed resolution of the variable speed limit signs is very coarse, and these signs are generally not very well obeyed. Dynamic speed assistance, also in the sense that it would temporarily change from warning to control mode in a motorway situation, could address this, and could also greatly improve the effect of speed assistance on the homogeneity of the traffic flow when needed. The models to be applied are quite complicated, and it would require fully automated floating vehicle data collection and processing, a position dependent dynamisation of the speed limit, and provision of this information to the vehicle. Transmission is best done locally, by means of short-range communication. Extensive field operational testing of such system would be necessary, and could provide a platform for large-scale real world testing of traffic flow models. Obligatory lane keeping in dense traffic conditions could also contribute to solve congestion, but is difficult to implement with current technology.

Integration of navigation with speed assistance, based on a platform with a central map server and vehicle positioning unit, could offer the potential for a mass market, and make prices drop considerably. The technology is state-of-the-art, and would be short-term deployable. Fiscal measures and lower car insurance premiums may contribute to foster acceptance if authorities decide for voluntary introduction. However, authorities may also choose obligatory introduction, as a better tool for speed limit enforcement. Mentioned platform, if also equipped with an driving assistance system interface, can also be used by other system functions as well as for road pricing and the motor vehicle black box.

## CORE TECHNOLOGIES: POSITIONING AND COMMUNICATION

Positioning and communication are core technologies for collision avoidance, intersection support and lane keeping. Different options are available, and these can be combined in different ways to create autonomous systems and co-operative systems. For both technologies we will first give a short review of currently available alternatives. Available does not necessarily mean off-the-shelf. It means that the concepts exist. Some of these concepts are mature, but most of them still need considerable improvement by further research and extensive implementation testing, since they do not currently meet fundamental requirements regarding robustness, including reliability, permanent and fail-safe operation, and few or no false alarms. A further important variable is whether such systems are used in a warning or control mode, or a combination of both. And for the warning mode the choice of the HMI is a key factor. Another issue is sensor fusion, to improve robustness, reliability and operation permanence. It is also important to distinguish collision avoidance between two (or more) vehicles, and between a vehicle and (one or more) vulnerable road users (VRUs).

For positioning two different concepts may be distinguished. Relative positioning determines the position and velocity (speed and direction) of the vehicle relative to the road infrastructure and to other objects (stationary and moving), by using some kind of imaging sensor and image processing. Suitable sensors for this include radar (radio detecting and ranging), lidar (light detecting and ranging), and visible light and infrared imaging. Active sensors (radar, lidar) measure the reflections of signals that first were transmitted by the same sensor. Optical and infrared sensors are generally used (in automotive applications) in a passive sense, by measuring the radiation that is naturally transmitted by objects, although they may be used in an active mode by preceding illumination of objects. Another relative positioning method is the use of magnetic lane markers. Absolute positioning uses satellite positioning, preferably in combination with inertial sensors and map data, to provide an absolute position, as well as velocity. Relative positioning sensors are in the first place used in autonomous solutions, while the use of absolute positioning for collision avoidance requires bi-directional communication to issue the vehicle's position and velocity as well as to acquire position and velocity data of other nearby vehicles. Relative positioning may be used to avoid vehicle-vehicle encounters as well as vehicle-VRU encounters. Absolute positioning is not appropriate to avoid the latter type of collisions.

### Relative Positioning

Different types of radar are being used or investigated for automotive applications. ACC systems that are already on the market use frequency modulated continuous wave (FMCW) long range radar (LRR, range up to 150 m) in the 76-77 GHz millimetre-wave band. Ultra wide band (UWB) pulse operated short range radar (SRR, range up to 50 m) in the 24 GHz centimetre-wave band is proposed and tested for automotive applications [Molish 2003]. SRR is at current prices a factor 40 cheaper per unit than LRR [Marsh 2003], has smaller size and better penetrates bumper materials, which makes it easier to implement several (or an array) of such sensors in a vehicle. However, in Europe serious regulatory issues needed to be solved, and it is even debated if 24 GHz is the best solution. A large number of car manufacturers and system suppliers united in the SARA (Short range Automotive Radar frequency Allocation) Group is strongly promoting global harmonisation and regulation for this type of radar, especially for the use in applications to enhance road safety [Scherrer 2003]. Radar is insensitive to bad weather and environmental conditions, but it cannot "see" the (course of the) road.

Lidar imaging uses a highly directional beam of laser light in a scanning mode. It is less expensive than radar and easier to package. However, it is sensible for poor visibility, especially rain and snow, as the width of the light beams is less than the size of water droplets. Furthermore, dust, mud and snow on the car can easily block lidar beams. [Jones 2001]

Visible image processing for automotive applications is being pursued from 1987, with a boost since the Prometheus project in the early nineties [Franke 2002]. Although good progress has been made, prices of the necessary equipment have gone down, and stereo imaging makes distance determination possible, it seems to remain difficult to make the systems robust and sufficiently discriminatory with respect to different types of objects. Especially bad weather and adverse ambient conditions may drastically deteriorate the performance of these systems, while their operation during night-time may also be problematic. A clear advantage compared to radar is that vision systems in principle (dependent on clear road markings or other well visible road characteristics) are able to distinguish the road. Therefore it is obvious, for certain applications, to integrate radar and vision systems. Infrared sensors in principle can add night time vision capability, and better penetrate bad weather conditions.

In general, the application of these remote relative positioning sensors to detect road traffic hazards in complex traffic situations is more problematic, in terms of response time, accuracy and reliability, than their use for measuring less critical phenomena like e.g. general traffic flow conditions. [Wang 2004]

## **Absolute Positioning**

Current stand-alone, code based satellite positioning (GPS) allows a horizontal accuracy of about 10 m, and in combination with inertial sensors and a digital map of about 5 m. Performance of GPS may be improved by differential corrections. A Wide Area Augmentation System (WAAS) like the European Geostationary Navigation Overlay System (EGNOS) may be a solution for pan-European use of ITS applications, although accuracy will not be better than about 2 m. Also the signal of the geostationary satellite may sometimes be blocked, much like the signals of the GPS satellites themselves may be temporarily blocked by buildings (the urban canyon), foliage, mountains, or in tunnels. In a navigation system these satellite outages are sufficiently covered by the inertial sensors (relative positioning) and the digital map. More precise carrier-phase based positioning would be possible (to the cm level in combination with differential corrections), but the resolution of the initial cycle ambiguity parameters takes time, and each cycle slip (discontinuity in the carrier-phase measurements due to a temporarily blocked satellite signal) makes that this process has to start over again. [El-Rabbany 2002] Galileo plans to provide a safety related service of 4 m or better horizontal accuracy (95 percent) based on dual-frequency measurements [GISS 2002]. As a conclusion it can therefore be said that sub-meter positioning using satellite technology in moving vehicles seems difficult to achieve. Use of a position with sub-meter accuracy would require a map database of similar or better accuracy, of which the economical feasibility yet has to be demonstrated [NextMAP Consortium 2000]. A proposed solution to cover satellite outages is the use of pseudolites (local augmentation) [El-Rabbany 2002], but it is questionable if this is cost-effective and useful if sub-meter level positioning is not possible.

## Communication

Two different scenarios of medium distance communication are envisaged for road safety and traffic management applications: vehicle-to-vehicle (v2v) communication, using peer-to-peer, self-organising ad-hoc mobile radio networks (distributed, multi-hop), and vehicle-to-infrastructure (v2i), using master-slave, infrastructure centralised, one-hop mobile networks between vehicles and fixed roadside beacons. [Huang 2002, Ohmori 2001, Zhu 2003]

The proposed medium for this type of communication will use the IEEE 802.11a R/A (Roadside Applications) protocol, a variant of the Wireless LAN (Local Area Network) standard, in the 5.9 GHz band adjacent to the DSRC (Dedicated Short-Range Communication) spectrum, and is developed as application M5 (Microwave 5 GHz) of the CALM architecture (Continuous Air interface for Long and Medium distance) in the framework of ISO TC204/WG 16 [Andresen 2003]. The v2i links are intended to support a wide range of applications (including multimedia, entertainment and internet access), and therefore must support high data transfer rates. Stated data rates are 54 Mbps up to 80 m and 6 Mbps up to 1000 m [Evensen 2003]. Various issues still need to be solved, and first-generation devices are expected by 2005, and full capability devices by 2010. An advantage of using the 5 GHz spectrum is that it can penetrate walls and propagate around corners. This development was initiated from the US, but has been adopted by the ITS community worldwide, although Europe has been remarkably slow in taking up this approach. [Evensen 2003] The eSafety final report [EC 2003] e.g. recommends identification, and where necessary development of new specifications for interfaces and communications protocols for v2v and v2i communications, but does not reference CALM M5. In Europe, research on cooperative systems in general is in its infancy, but may get a boost with two large EU funded Integrated Projects on cooperative systems being prepared and expected to start early 2006: SAFESPOT with focus of traffic safety applications, and Cooperative Vehicle Infrastructure Systems (CVIS), with focus on traffic efficiency.

## COLLISION AVOIDANCE

Much research is ongoing on the development of autonomous sensing systems for the car with the aim of both avoiding collisions and mitigating the impact of collisions once they cannot be avoided. An ultimate configuration is a 360° car surround sensing system (providing a "virtual safety belt" around the car) with an approximate number of 10 SRR units per vehicle for luxury cars for all kinds of functions, including crash mitigation [Marsh 2003, Scherrer 2003], and one LRR unit at the front side of the car, possibly combined with video image processing, for crash avoidance.

Clearly, from a perspective of replacing infrastructure measures that are meant to be all encompassing, such systems would only contribute sufficiently at high market penetration rates. Given the regulatory problems with the 24 GHz UWB systems, and the recent decision of the European commission to limit market penetration of such systems to 7 percent until 30 June 2013, to accommodate expected interference problems, and no further implementation in new cars after that date [EC 2005], it may be doubted if these systems will play an important role in traffic safety until 2010. For LRR and vision the implementation scenario is different, although here the cost of the system may be prohibitive to induce a large market penetration before 2010.

Relevant aspects of these sensor technologies have been studied in recent years by several EU funded projects, which are presented here as examples. The RadarNet project implemented one multi-beam narrow-angle 77 GHz radar for detection up to 150 m, and an array of four 77 GHz single-beam radar sensors for a range up to 25 m, for an urban rear-end collision avoidance system for vehicle speeds up to 80 km/h. Use of only 77 GHz technology was seen as an advantage, as it is the same as used for ACC. [RadarNet Consortium 2004] The SAVE-U project developed a near-by sensing system for VRUs, for speeds up to 40 km/h, which combined passive infrared and visible spectrum imaging and a network of several parallel 24 GHz radar sensors, to make it robust in all weather and lighting conditions. Human obstacle recognition was improved by use of a large database of VRU images. [Meinecke 2003] The CARSENSE project combined information from laser, radar, visible spectrum imaging and the vehicle dynamics sensors in a system for low speed driving assistance in complex urban situations. [Langheim 2002]

Of course these projects show only a fraction of all the research of such systems that is undoubtedly in progress at car manufacturers, in co-operation with system suppliers. Nevertheless one cannot escape the conclusion that these and similar projects are still very much in the experimental stage, and need follow-up projects in order to develop systems that are really robust and have an acceptable cost price.

Cooperative systems provide another approach, at least conceptually, for rear-end collision avoidance, by use of vehicle positioning and v2v communication. To make this work in a robust manner, the communication needs to be robust, and the positioning needs to be robust and of high accuracy. Although the standards work on the M5 application in the CALM framework is on its way, it still has some time to go, and its adoption in Europe may even take longer, as stated before. But it is to be expected that M5 based v2v communication can eventually be progressed to a state of maturity and robustness. For the vehicle positioning it is maybe a different matter. On a multi-lane road such system should provide lane discrimination: in which lane the vehicle is, and where in that lane. This would require a horizontal accuracy of about 0.3 m, which, as stated before is difficult to achieve. If this would be achievable, also a highly precise digital map would be required, of which the practical and economical feasibility yet needs to be demonstrated. Only a system using magnetic lane markers would be able to provide the stated precision.

The EU funded project CARTALK2000 investigated a cooperative longitudinal control system, using positioning based on differential GPS and inertial sensors, and an ad-hoc mobile communication network based on UMTS terrestrial radio access network (UTRAN) technology [Maihöfer 2004]. The limited set-up of the work, in view of the original plans, using only three vehicles, and concentrating on "the transparent front" vehicle, is another indication that it is still a long way before such systems will be mature and ready for large-scale implementation. Also, for this type of applications follow-up projects may be necessary, and practical use is not to be expected before the end of this decade. In Germany, the FleetNet project developed position-based routing in vehicular ad-hoc networks [Füßler 2003], and the follow-up project Network on Wheels (started in 2004) tries to increase robustness and reliability of the methods in real-world radio environments, including cities.

## INTERSECTION SUPPORT

In the US extensive research has been carried out on infrastructure based cooperative intersection collision avoidance systems [BMI 2003, Pierowicz 2000]. Also autonomous and v2v cooperative approaches may be used for collision avoidance at intersections. The reliability of autonomous systems will, more than for longitudinal collision avoidance, be hampered by the fact that an unobstructed line of sight, a *conditio sine qua non*, is sometimes not available. Therefore a cooperative approach seems to be the better option. Performance may be enhanced, but also complexity and cost increased, by an integration of autonomous and cooperative solutions. Both approaches have also for intersection avoidance the prospect that large-scale market availability at affordable prices before the end of the decade may be doubted. For the longer term a cooperative system for intersection support could be envisaged that goes a step beyond mere collision (hazard) avoidance, and operates in an intersection negotiation mode. In Japan research has been carried out on v2v and v2i communication based intersection support [Morimoto 1999].

However, the cost-effectiveness of intersection support is doubted. For instance, red-light running accounts for the vast majority of the more than one million annual collisions at signalled intersections in the US, which cause over 500,000 injuries, several thousand fatalities, and related costs of about US\$ 7 billion annually [Joseph 2001]. Speed is a crucial aggravating factor at intersection collisions. Intersection support could be one of the countermeasures, but would hardly contribute to a better protection of VRUs (pedestrians and cyclists). Speed assistance enhanced with a function to control vehicle speed at *any* intersection, and with beacon augmentation to avoid red light running, might well bring more significant safety effects, as it takes into account VRUs as well, reduces the consequences of speed, and all of this with a much simpler system layout. Moreover it may help to counteract congestion in metropolitan areas by reducing the variation in vehicle speeds, thereby making traffic flows more homogeneous.

## LANE KEEPING

Much of the ongoing lane keeping research and development relates to lane keeping on motorways and to the prospect of future autonomous vehicle guidance on such roads. Certainly a reliable lane keeping system for motorways can have certain safety benefits, but the focus in this article is on lane keeping for extra-urban two-lane single carriageway roads for through traffic, as these contribute significantly to traffic unsafety. For such roads it has been proposed (for instance in the Netherlands) to implement everywhere physical lane separation, prohibiting overtaking and avoiding midline crossing due to inattention. However, the costs of this measure have proven to be prohibitive.

Lane keeping based on absolute positioning would require a horizontal accuracy of about 0.3 m, which, as stated before, seems difficult to achieve. A system based relative positioning by video cameras and line recognition is very dependent on the quality of the line(s) on the road, and not sufficiently reliable in adverse weather, lighting and ambient conditions. Such type of system is available on the market, both for trucks (MAN, DC) and cars (Citroën).

Another method of relative positioning, based on magnetic lane markers, was developed in the US [Chan 2003], in the first place for autonomous vehicle guidance. However, it could provide a feasible and cost-effective alternative for safety related lane keeping on extra-urban single carriageway through roads, with sub-decimetre lateral accuracy. Magnetic position markers are installed under the road surface at the lane centreline, at regular distance, typically 1-2 m, and the lateral position of the vehicle with respect to the centreline is determined by magnetic sensors in the vehicle. A similar type of lane marker system uses

passive radiofrequency multiplier position markers, also under the centreline, that reflect micropower radio waves transmitted from the vehicle. Tests in Japan showed that both systems can provide a lateral positioning accuracy of 4 cm or better at speeds between 20 and 120 km/h. [AHSRA 2003]. Of course such systems require an infrastructure component, which brings additional cost, but a clear advantage is that their operation is independent of weather, lighting and ambient conditions. Also, the equipment in the car is relatively inexpensive, and the durability and lifetime of the infrastructure component is high. A third method in this category is based on magnetic tape, which can be used in combination with the normal white lane markers, which nowadays are often also applied in the form of tape instead of the traditional painting. Painting in itself is cheaper, but tape lasts longer, making it overall more attractive. The tape has been extensively tested for snowplough guidance [Mn/DOT 2001].

## CONCLUSIONS

Of the various technologies that are discussed in this paper, navigation is mature and speed assistance options are in development, pointing the way to large-scale implementation. However, complete and up-to-date coverage of speed limits in digital map needs to be organised. In general, the introduction of integrated speed assistance and navigation may reduce the need for, and urgency of the various other systems that are being developed, as most safety effects will be achieved cost-effectively by these two integrated systems. Furthermore, they may establish a platform in the vehicle for future integration of other driving assistance system applications, as well as contribute to traffic flow improvement [Hegyi 2004]. Other technologies that are mature and could be easily large-scale applied are lane keeping by use of magnetic line marking and computer vision.

The other discussed technologies (based on radar, laser, video imaging, communication and/or satellite positioning) are promising, and can also contribute to traffic safety, but need still considerable improvement in robustness, reliability and cost. The difficulties do not only relate to the sensor technologies that are being employed, but also to other design parameters, like e.g. the algorithms for reliable detection of VRUs. Systems based on v2v communication and vehicle positioning seem conceptually to be the most promising, although they do not take into account VRUs.

## ACKNOWLEDGEMENT

This paper is a result of the EU funded project IN-SAFETY (Infrastructure SAFETY, FP6). It is also a result of a PhD study, part of the research programme BAMADAS (Behavioural Analysis and Modelling of Advanced Driver Assistance Systems), funded by the Dutch National Science Foundation (Connekt/NWO).

## REFERENCES

- ActMAP Consortium, *AtMAP Specification*, Deliverable 3.2, Version 1.0, Brussels, 30 September 2004.
- AHSRA (Advanced Cruise-Assist Highway System Research Association), *AHSRA report*, vol.11, Tokyo, October 2003.
- A. Alessandri, A. Di Febbraro, A. Ferrara, and E. Punta, *Nonlinear optimization for freeway control using variable-speed signalling*, IEEE Transactions on Vehicular Technology 48, no.6, pp.2042-2052, November 1999.
- S. Andresen and K. Evensen, *Standardisation and trends - Why is standardisation of ITS needed?*, Telektronik, vol.1, 2003.
- BMI (Bellomo-Mcgee Incorporated), *Intersection collision avoidance study: final report*, US DoT (Department of Transportation), FHWA (Federal Highway Administration), Columbus, Ohio, September 2003.
- C.Y. Chan, H.S. Tan, *Evaluation of Magnetic Markers as a Position Reference System for Ground Vehicle Guidance and Control*, California PATH Research Report UCB-ITS-PRR-2003-8, California Partners for Advanced Transit and Highways, March 2003.
- C.-C. Chien, Y. Zhang, and P.A. Ioannou, *Traffic density control for automated highway systems*, Automatica, vol.33, no.7, pp.1273-1285, 1997.
- EC (European Commission), *Final Report of the eSafety Working Group on Road safety, November 2002*, Office for Official Publications of the European Communities, Luxembourg, 2003.
- EC (European Commission), *Commission decision of 17 January 2005 on the harmonisation of the 24 GHz range radio spectrum band for the time-limited use by automotive short-range radar equipment in the Community*, Official Journal of the European Union, 25 January 2005.
- A. El-Rabbany, *Introduction to GPS, The global positioning system*, Boston, London: Artech House, 2002.
- K. Evensen, *CALM versus DSRC - complementary technologies*, In Proceedings of the 10th World Congress on ITS, Madrid, November 2003.
- U. Franke and S. Heinrich, *Fast Obstacle Detection for Urban Traffic Situations*, IEEE Transaction on Intelligent Transportation Systems, vol.3, pp.173-181, September 2002.
- H. Fùbler, J. Widmer, M. Käsemann, M. Mauve, and H. Hartenstein, *Contention-based forwarding for mobile ad hoc networks*, Ad Hoc Networks, vol.1, pp.351-369, 2003.
- GISS, *Galileo Mission requirements document*, Issue 5 (draft), Brussels, 25 July 2002.
- A. Hegyi, *Model predictive control for integrating traffic control measures*, Dissertation, TRAIL thesis series T2004/2, Delft, 2004.
- Q. Huang, R. Miller, P. MacNeille, G. Roman, and D. DiMeo, *Development of a peer-to-peer collision warning system*, Ford Technical Journal, vol.5, no.2, March 2002.
- W. D. Jones, *Keeping cars from crashing*, IEEE Spectrum, vol.38, pp.40-45, September 2001.
- J. Joseph, *Stopping on red*, Traffic Technology International (TTI), pp.40-47, Aug/Sep 2001.
- R. Kates and K. Bogenberger, *Potential for improved traffic performance using inter-vehicle communication and distributed intelligence*, In Proceedings of the 10th World Congress on ITS, Madrid, November 2003 (INVENT - "intelligent traffic and user-friendly technology" project).

- J. Langheim, A. Buchanan, U. Lages, and M. Wahl, *CARSENSE - New environment sensing for advanced driver assistance systems*, In Proceedings of the 10th World Congress on ITS, Chicago, October 2002.
- H. Lenz, R. Sollacher, and M. Lang, *Standing waves and the influence of speed limits*, In Proceedings of European Control Conference, pp.1228-1232, Porto, 2001.
- M. Lu, R. van der Heijden, and K. Wevers, *Traffic safety - road infrastructure versus ITS*, In Proceedings of the 10th World Congress on ITS, Madrid, November 2003.
- C. Maihöfer and R. Eberhardt, *Time-stable geocast for ad hoc networks and its application with virtual warning signs*, Computer Communications, vol.27, pp.1065–1075, 2004.
- MAPS&ADAS Consortium, *Interface and Data Entity Specifications*, version 10, Brussels, 26 January 2005.
- D. Marsh, *Radar reflects safer highways*, EDN, 24 April 2003.
- M. Meinecke, M.A. Obojski, M. Töns, R. Doerfler, P. Marchal, L. Letellier, D. Gavrila, and R. Morris, *Approach for protection of vulnerable road users using sensor fusion techniques*, International Radar Symposium, Dresden, Sept 30-Oct 2, 2003 (SAVE-U project).
- Mn/DOT (Minnesota Department of Transportation), *Detailed design, Intelligent Vehicle Initiative - Specialty Vehicle Field Operational Test*, Mn/DOT - US DOT Cooperative Agreement DTFH61-99-X-00101, Saint Paul, August 2001.
- A. Molish and J. Zhang, *Ultra wideband systems*, Wireless Technology, 2003.
- H. Morimoto, M. Koizumi, H. Inoue, K. Nitadori, *AHS road-to-vehicle communication system*, IEEE Intelligent Transportation Systems Conference, pp. 327-334, Tokyo, October 1999.
- NextMAP Consortium, *Roadmap of preliminary enhanced map database requirements*, NextMAP Consortium, Deliverable D 2.1, final version 2.0, Brussels, 25 August 2000 (restricted).
- S. Ohmori, T. Horimatsu, M. Fujise, and K. Tokuda, *Radio communication technologies for vehicle information systems*, in L. Vlacic, M. Parent and F. Harashima (eds), Intelligent vehicle technologies, Butterworth, 2001.
- M. Peden, R. Scurfield, D. Sleet, D. Mohan, A.A. Hyder, E. Jarawan, and C. Mathers, *World Report on Road Traffic Injury Prevention*, World Health Organization (WHO), Geneva, 2004.
- J. Pierowicz, E. Jocoy, M. Lloyd, A. Bittner, and B. Pirson, *Intersection collision avoidance using ITS countermeasures*, Final report, DOT HS 809 171, US Department of Transportation, Washington D.C., 2000.
- RadarNet Consortium., *Multifunctional Automotive Radar Network (RadarNet)*, RadarNet Consortium, Deliverable D40, Final Report version 0.5, Regensburg, 25 November 2004.
- SafeMAP Consortium, *Socio-economic assessment of a dedicated digital map for road safety applications, Project description*, Paris, 2003 (restricted).
- D. Scherrer and R. Burgherr, *Short Range Devices, Radio Frequency Identification Devices, Bluetooth, Ultra Wideband Systems, Automotive Short Range Radars, Overview and latest developments*, OFCOM (Swiss Federal Office of Communications), Biel, 31 October 2003.
- D.J. Sentinella and E.J. Hardman, *Review of motorway speed control systems in Europe*, Unpublished Project Report. TRL, PR/TT/056/96 N203, Crowthorne, England, 1996.
- S. Smulders, *Control of Freeway Traffic Flow*, CWI Tract no. 80, CWI (Dutch institute for research in Mathematics and Computer Science), Amsterdam, 1996.

SpeedAlert Consortium, *Harmonisation of in vehicle speed alert system*, Detailed description of the proposal, Brussels, 2003 (restricted).

TMC Forum, *Precise location referencing*, TMC Forum Specification, Brussels, 20 September 2004.

X. Wang, C. Chan, J. Misener, S. Shladover, and W. Zhang, *Limiting factors in the use of remote sensors to detect road traffic hazards*, In Proceedings of TRB 83rd Annual Meeting, Washington D.C., January 2004.

J.K. Wilkie, *Using variable speed limit signs to mitigate speed differentials upstream of reduced flow locations*, Tech. rep., Department of Civil Engineering, Texas A&M University, College Station, Texas, 1997.

J. Zhu and S. Roy, *MAC (Media Access Control) for DSRC (Dedicated Short Range Communications) in Intelligent Transport System*, Communication Magazine, December 2003.

## APPENDIX: Overview of Safety Related Driving Assistance Systems

system function	definition and/or description	level	impact
navigation system	provision of vehicle positioning, route calculation and route guidance	I + S	lon
adaptive cruise control (ACC)	automatic control of speed and distance in relation to the proceeding vehicle in the same lane	C	lon
adaptive light control (ALC)	dynamic aiming headlamps and situation adaptive lighting	S	lon
vision enhancement	assist the driver's vision capability in adverse lighting and weather conditions by providing enhanced visual information.	S	lon
legal speed limit assistance	assist the driver in keeping within (static or dynamic) legal speed limits	I / W / C	lon
curve speed assistance	assist the driver in keeping within an appropriate and safe speed in a curve	W / C	lon
dangerous spots warning	assist the driver by providing information or warning on a dangerous location (based on accident statistics) at inappropriate speed	I / W	lon
stop and go (S&G)	assist the driver by taking over full vehicle control in congested stop-and-go traffic at low speeds (automated lane keeping and platooning)	C	lon
anti-collision systems	assist the driver to avoid imminent forward collisions  two possible modes: - warning - warning followed by automatic control if necessary  three possible system layouts: collision warning, collision mitigation and collision control	W / C	lon
lane keeping assistant (LKA) (= lane departure avoidance)	assist the driver to stay in lane (on unintentional lane departure or road departure)  three possible modes: - warning (e.g. by rumble strip sound) - semi-control of the vehicle (by force feedback on the steering wheel) - full control	W / C	lat
lane change assistant (LCA) (= lateral collision avoidance)	for change-of-lane manoeuvres, provide information about vehicles in adjacent lanes, and/or warning for potential collision, and/or vehicle control in case of imminent collision	I / W / C	lat
intersection collision avoidance (ICA)	avoid collisions at intersections by warning or control  two types are foreseen: - based on radar and/or vision - based on vehicle positioning and short-range communication, requires all participating vehicles to be equipped	W / C	lon
intersection negotiation	regulate motor vehicle traffic at intersections based on vehicle positioning and short-range communication in all participating vehicles	C	lon
autonomous driving	fully automated driving in controlled motorway situations at all speeds by full lateral and longitudinal control	C	lat + lon

Source: partly based on [NextMAP Consortium 2000]

Level: I = information, W = warning, C = control, S = support

Impact: lon = longitudinal, lat = lateral