Three Decades of Driver Assistance Systems

Review and Future Perspectives

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Abstract—This contribution provides a review of fundamental goals, development and future perspectives of driver assistance systems. Mobility is a fundamental desire of mankind. Virtually any society strives for safe and efficient mobility at low ecological and economic costs. Nevertheless, its technical implementation significantly differs among societies, depending on their culture and their degree of industrialization. A potential evolutionary roadmap for driver assistance systems is discussed. Emerging from systems based on proprioceptive sensors, such as ABS or ESC, we review the progress incented by the use of exteroceptive sensors such as radar, video, or lidar. While the ultimate goal of automated and cooperative traffic still remains a vision of the future, intermediate steps towards that aim can be realized through systems that mitigate or avoid collisions in selected driving situations. Research extends the state-of-the-art in automated driving in urban traffic and in cooperative driving, the latter addressing communication and collaboration between different vehicles, as well as cooperative vehicle operation by its driver and its machine intelligence. These steps are considered important for the interim period, until reliable unsupervised automated driving for all conceivable traffic situations becomes available. The prospective evolution of driver assistance systems will be stimulated by several technological, societal and market trends. The paper closes with a view on current research fields.
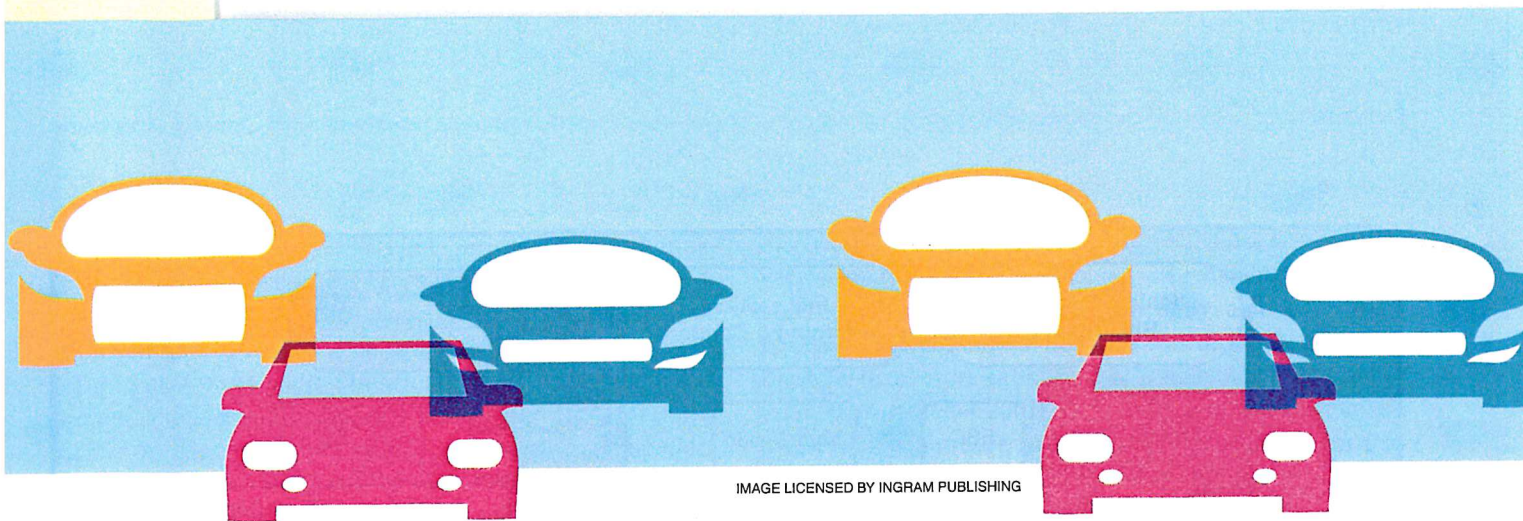
1. Objectives of Mobility and Driver Assistance

Mobility is highly correlated with societal and individual well-being and greatly contributes to quality of life. It is the backbone of commercial trading and services and, therefore, the basis for economic success. Through mass automobile production and strategic, long-term paved road creation, industrialized countries have reached a high degree of individual mobility.

Its advantages, however, come at a price. In addition to obvious monetary costs of vehicles, fuel, and the provision and maintenance of automobile infrastructure, mass mobilization entails further economic, ecological, and social costs: resource consumption, noise and exhaust pollution, loss of productive time due to traffic congestion and harmful or fatal traffic incidents as a personal safety risk are merely a select few examples of adverse effects (Verhoef 1994, Schrank et al. 2012, Holden 2012).

While the focus of the mobility industry is partly shifting towards emerging markets where the need for individual mobility is not yet as saturated, automobile markets in highly industrialized countries like Germany mainly aim to raise the quality of today's mobility. This goal includes a reduction of traffic related accidents (keyword: "vision zero": Vision zero is the image of a future in which no one will be killed or seriously injured by traffic accidents) (Vägverket, 2014) and environmental pollution, as well as an increase of mobile efficiency in terms of energy, time, and resources (European Union 2010).

Measures to reduce the costs of mobility per distance driven have been taken since the 1970s, e.g. the development of passive passenger safety concepts, low-emission vehicles, and safer traffic routes. In order to further diminish the negative impact of mass mobilization on economy, environment, and society, new strategies have to be devised.

A frequently discussed concept is the electrification of automobiles with the aim of reducing ecological costs and countering the increasing scarcity of resources. Despite the solutions electric cars offer in response to the disadvantages of ordinary automobiles, the reasonability of mass electrification is still open to dispute (Ogden et al. 2004). For the purposes of this article, electro-mobility will be considered a possible long-term approach, but not a dominant choice for the near future.

A different approach to increase the efficiency of mobility is the concept of driver assistance. Driver assistance systems (DAS) offer a means to enhance, among other things, active and integrated safety. However, in order to maximize their contribution to overall traffic safety, an increased market penetration is required (Lu 2006). This can be achieved by raising awareness for DAS and their benefits throughout the population, or by regulating their implementation by law. A good example for the latter is, e.g. electronic stability control systems (ESC), which are mandatorily included in newly produced vehicles throughout the traditional markets (e.g. from November 2014 on in the EU, (European Union 2008)).

In order to tap the full potential of DAS, increased emphasis should be put on "special needs" of driver groups, such as first time drivers or elderly drivers. By adapting to the specific needs of such drivers, DAS can probably better help reduce traffic related fatalities, which amount to 1.2 million people worldwide (Volvo 2013). While the majority of these fatalities occur within the vehicle, safety vulnerable traffic participants, i.e. pedestrians, bicyclists, and motorcyclists, must not be neglected. The potential contribution of passive safety, such as bluff vehicle bodies, is very limited. Active collision protection systems with emergency braking and collision mitigation capabilities, despite the technical challenge they represent, can be considered indispensable in order to truly decrease traffic-related fatalities.

When forming future concepts, it is necessary to maintain an integral and systematic perspective. PROMETHEUS (1987–1995), a European research project dedicated to the improvement of mobility quality, showed that success is not merely dependent on technological feasibility (Nagel 2008). The California PATH program established in 1986 was a multi-disciplinary US initiative with a similar integral perspective including automated Highways (PATH 2014). Other projects for future concepts include SARTRE and DRIVE, both of which were funded by the European Commission. SARTRE aimed to encourage a change in personal transport by platooning. The unique element of the program was the interaction between the lead vehicle and
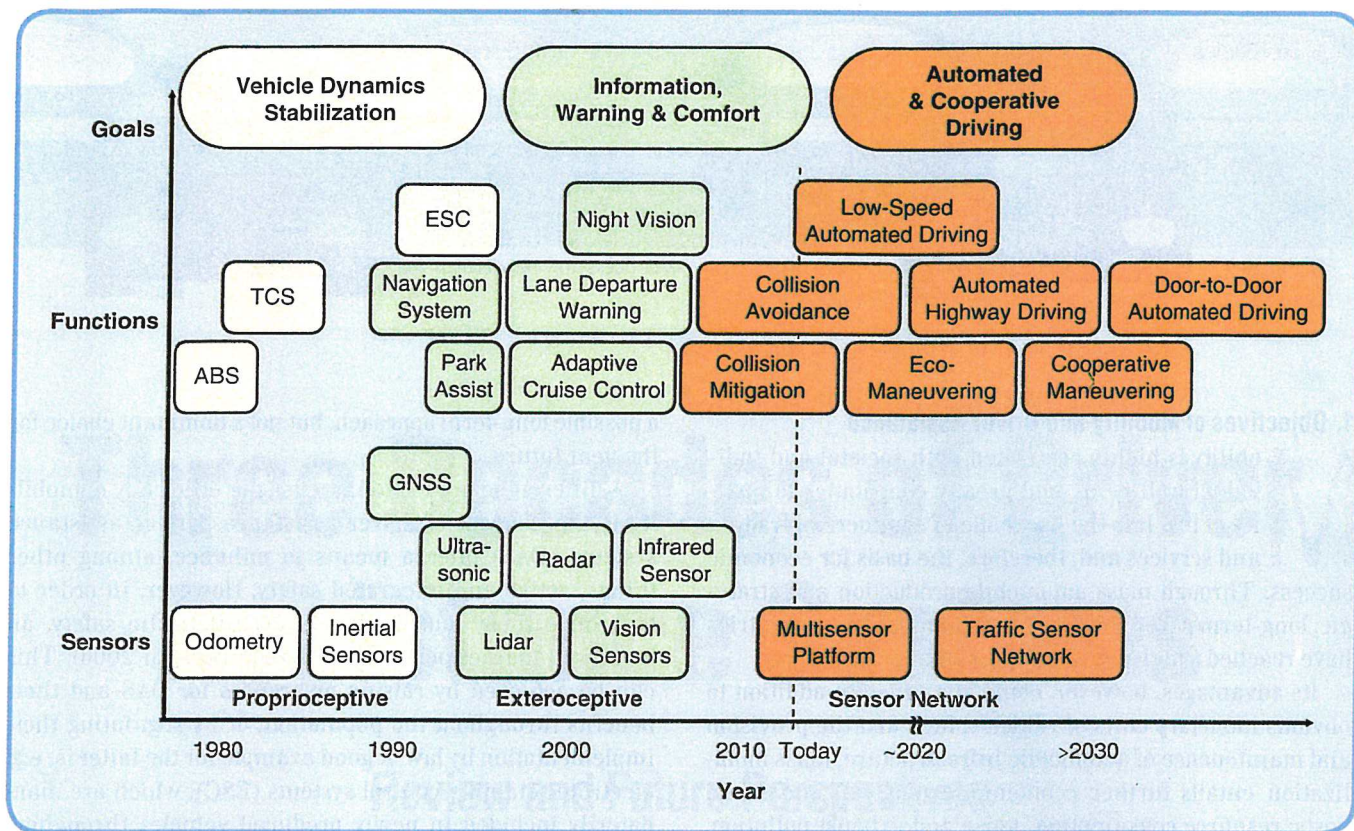
FIG 1 Past and potential future evolution towards automated cooperative driving.

the following vehicles. The introduction of platooning was predicted to achieve environmental as well as safety benefits and a reduction of congestions (SARTRE).

2. Current State of Technology, Research, and the Market

Evolution of Driver Assistance Functions
from a Market Perspective
The past and a potential future evolution of DAS is sketched in Fig. 1 from a technological point of view[1].

Early DAS were based on proprioceptive sensors, i.e. sensors measuring the internal status of the vehicle, such as wheel velocity, acceleration, or rotational velocity. These enable the control of vehicle dynamics with the goal of following the trajectory requested by the driver in the best possible way.

One of the first active assistance systems based on proprioceptive sensors was the Anti-lock Braking System (ABS), with serial production from 1978 (Bosch). A Traction Control System (TCS) later augmented the system. Years later in 1995, the introduction of additional dynamic driving controls, such as Electronic Stability Control (ESC), marked a further milestone in assistance development (van Zanten

& Kost 2012). With ESC, an electronic gyroscope found its way into the automobile. This equipment did not only lay the foundation for the ESC, but revealed an entire range of additional usage possibilities. Overall component price was reduced twofold by emphasizing cost efficiency in the production process. In terms of road safety, studies have shown that dynamic driving controls are the second most efficient safety system for passengers, outmatched only by the seatbelt (Aga et al. 2003, Sferco et al. 2001). This was strikingly demonstrated in the Mercedes A-Class "Moose Test", which caught the attention of the media, see e.g. (Andrews 1997, Strassmann 1988). With the public recognition of the safety potential of dynamic driving control systems, the frequency of implementation for such systems increased significantly, and they have, in consequence, saved several thousands of lives. Starting November 2014, ESC (in addition to braking assistance systems developed at the same time) will even be a legal requirement in each new car in the EU.

Exteroceptive sensors acquire information from outside the vehicle, including ultrasonic, radar, lidar or video sensors and to some extent Global Navigation Satellite System (GNSS)[2] receivers. These sensors provide information about the road ahead and the presence as well as the driving status of other traffic participants or the vehicle's position in the world. The international evolution in the area

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[1]The figure sketches the dates of market introduction for selected DAS functions to the best knowledge and understanding of the authors. Nevertheless, the selection of the first market introduction for a specific DAS function depends on the detailed definition of several factors, like functional specifications, serial size, and market acceptance and retention.

[2]GNSS summarizes GPS, Galileo, and GLONASS for satellite-based localization.

of navigation systems in relation to progress in positioning technology is described in (Akamatsu et al. 2013)

The second generation of driver assistance functions first introduced around 1990 based on exteroceptive sensors focuses on providing information and warnings to the driver, and on enhancing driving comfort. Substantially driven by the cost reduction of mobile devices navigation technology using GNSS has become prevalent in present-day vehicles. Due to the phenomenon of the "non-local risk", constituting that non-locals are involved in accidents more frequently than locals (Engels & Dellen 1989), navigation systems have safety implications. By aiding a driver in orientation, navigation systems hold the potential to reduce the driver's workload, allowing a greater amount of mental resources to be dedicated to the primary driving task, thereby reducing the risk of accidents due to inattention (TNO 2007). Additionally, several studies indicate the advantages in saving gas/fuel by anticipatory driving and travelling to a destination via the optimal route (e.g. Zlocki et al. 2010, Bär et al. 2011, Boriboonsomsin et al. 2012, Dornieden et al. 2012, Popiv et al. 2010). With increasingly accurate navigation technology in the future, further beneficial effects are conceivable through the provision of localization data to support systems, enabling their functions to be better adapted to local driving conditions.

Parking assistance systems entered the market in the mid-1990s, e.g. (Katzwinkel et al. 2012). Ultrasonic sensors are used to detect obstacles in the surrounding environment. Initially, these systems had merely a warning function to help prevent collisions while backing into and out of parking spaces; later, they were complemented by rear-view cameras to better assist the driver with more detailed information. After electronically controllable steering became available, parking assistants became capable of entirely relieving the driver of lateral vehicle control during the parking maneuver, requiring him only to accelerate and brake. Over the years, this system's capability expanded from parallel to perpendicular parking. Additionally, video data of the vehicle's surroundings were upgraded from a simple rear view to one that spans an entire 360° (Nissan 2007). The market did not respond as fast to parking assistance systems as to ESC and navigation systems. However, considering that parking assistance systems are typically considered an optional feature and associated with additional costs, such systems have nonetheless been successful in their own right. So far, state-of-the-art of these systems is limited to automatic steering (Valeo 2013) into a parking space designated by the driver (and recognized by the vehicle), whereas a type of valet parking (where the driver is completely removed from the procedure of finding a parking space) may soon be technologically possible.

The development of Adaptive Cruise Control (ACC) (Winner et al. 2009, Winner 2012) set another milestone in driving assistance history. Through the implementation of electronic brake and drive control, and the use of previously very expensive radar technology, which in turn became significantly more affordable, partially automated driving was made possible. When ACC was introduced in 1999, these features were initially only usable at speeds greater than 30km/h (Jones 2001). Current systems with automatic transmission, however, have the ability to employ these features at lower speeds and, for example, to automatically follow other vehicles within traffic jam (TC204 2009).

Forward collision prevention systems using inexpensive low-range and low-resolution versions of lidar sensors are currently being used for low speed applications, marketed under the names: "City Safety" (Volvo 2014) and "City Stop" (Ford 2014). Both systems introduced around 2010 help to prevent car body damages, an economically very useful application. For advanced applications (e.g. higher speeds), the small detection range of inexpensive lidar systems is, however, a strongly limiting factor. Interestingly, long range collision mitigation systems based on the radar technology originally introduced with ACC had been introduced before in 2003–2006 (Kodaka et al. 2003). By means of escalating warning levels, the driver is made aware of an impending collision. If the driver does not react, the vehicle actively brakes to mitigate accident severity once a collision is no longer avoidable (Maurer 2012). Such systems have been investigated in the European PREVENT project (2004–2008), and can prove especially effective for larger vehicles such as trucks, due to their limited driving dynamics requiring earlier-onset braking in comparison to smaller vehicles. Consequently, these collision mitigation systems will be mandatory in new trucks in the EU by law, starting November 2013 (EC No 661/2009).

The same obligation exists for Lane Departure Warning (LDW) systems. These and the active lane keeping assistance systems derived from them, spawned the market entry of machine vision in the mobility sector and thereby constitute another milestone in DAS history (Ishida & Gayko 2004).

The latest class of DAS selects and controls trajectories beyond the current request of the driver. The high certainty level required for such decisions can only be achieved with an interconnected set of sensors. Radar and camera technologies currently dominate the DAS sector. Having complementary capabilities, an omission of one technology in favor of the other is not to be expected. Rather, data fusion strategies (Stiller et al. 2011) and joint sensor self-calibration (Dang et al. 2009) will combine the strengths of both technologies. The short-term goal is to automate driving in selected situations. As an example, traffic jam assistance systems have recently been introduced based on radar and stereo cameras. Merging longitudinal and lateral control, these systems are designed for Automated Low Speed Driving on congested highways assuming full lateral and longitudinal vehicle control at low speeds (Daimler 2013).

Maximum hands-off speed is still low (30 km/h), restricted to stop-and-go situations, but this function may eventually emerge towards automated highway driving.

Other extensions of current DAS are soon to come. Examples include an assistant for collision avoidance by evasive steering (Dang et al. 2012), assistants for the detection of oncoming traffic and pedestrians (Enzweiler & Gavrilla 2009) under adverse vision (weather) conditions (Roser & Geiger 2009), or assistants for improved intersection safety (Hopstock & Klanner 2007). Some of these systems require data exchange between traffic participants or with the road infrastructure, which is currently being investigated and demonstrated in field tests such as SIM-TD (2008–2013) (SIM-TD 2013), Ko-FAS (2009–2013) (Ko-FAS 2013), Koline (Saust et al. 2012), DriveC2X (2011–2013) (DRIVEC2X 2013). This approach promises an extension of a system's boundaries with respect to the availability of information and the expansion of its function to an entire collective of road users allowing for assisted or automated cooperative maneuvering (Stiller et al. 2007, Shladover 2009).

Research Towards Automated Driving

The ultimate DAS of the future should be capable of automated driving in all conceivable situations at a safety level significantly superior to that of a human driver and in cooperation with other traffic participants. This is considered especially important, as the compensation for human error, accounting for 90% of all accidents (Volvo 2013, Treat et al. 1979) is a prerequisite for accident-free traffic. In order to develop such cooperative automated vehicles, the driving tasks need to be broken up into basic functional components that can be technically implemented at a certified level of maturity.

Automated driving has already been a research topic since the late 1980s leading to e.g. the California PATH project (1986-ongoing), the NAVLAB project (1986-ongoing), (Thorpe 1990), the PROMETHEUS project (1987–1995) and the U.S. DOT National Automated Highway System Research Program (NAHS) (1994–1997). These projects have significantly advanced research in sensor hardware and software. In particular, e.g., lane recognition based on video capturing and processing technology has been demonstrated (Dickmanns & Mysliwetz 1992). In 1994 two demonstrator vehicles drove in normal traffic on Autoroute 1 near Paris demonstrating lane keeping up to 130 km/h, convoy and lane change maneuvers. The latter still required a manual confirmation by a safety driver. About 50 transputers processed images from four cameras extracting lane geometry and the pose of other vehicles. (Franke et al. 1994, Dickmanns et al. 1994). In 1995 an automated vehicle travelled from Munich, Germany, to Odense, Denmark, at velocities up to 175 km/h with about 95% in automated mode (Maurer et al. 1996, Maurer 2000). At about the same time another group demonstrated vision-based automated urban driving in the city of Karlsruhe at speeds of ca. 30 km/h. (Siegle et al. 1992, Nagel et al. 1995).

In the 'No hands across America' tour a vehicle drove from Washington DC to San Diego with 98% automated steering yet manual longitudinal control (Pomerleau 1995, Pomerleau & Jochem1996). The NAHS Demo'97 on I-15 in San Diego showed the capabilities of cars, busses and trucks in various automated highway scenarios. Various lane keeping technologies were presented using computer vision and based on augmented infrastructure like roadway embedded magnets and roadway laid radar-reflective stripes. Vehicle following was demonstrated using laser or radar sensors. Platooning with narrow headways was accomplished using inter-vehicle communication (Thorpe et al. 1997, Ozguner et al. 1997, Rajamani et al 2000). Likewise early contributions in Japan included public demonstrations of automated vehicles including Demo 2000 organized by the National Institute of Advanced Industrial Science and Technology. Cooperative platoon driving of five vehicles was demonstrated including advanced maneuvers such as stop-and-go, merging, and obstacle avoidance (Tsugawa & Sadayuki 1994, Kutami et al. 1995, Kato et al.2002).

Another long-distance mostly hands-free drive through Italy has been reported by (Broggi et al.1999). Multisensory automated driving without need for a safety driver onboard the vehicle has been realized on proving grounds (Stiller et al. 2001). Joint lateral an longitudinal control has been one of the main campaigns of the research programs INVENT (2001–2005) (Invent 2005) and AKTIV (2006–2010) (Aktiv 2012).

In the ongoing century several public challenges catalyzed international research on automated vehicles.

The Defense Advanced Research Projects Agency (DARPA) organized a first Grand Challenge for autonomous off-road ground vehicles in March 2004. The vehicles had to navigate a course of 175 miles through the desert defined by a dense series of some 2000 waypoints avoiding static obstacles. The furthest distance traveled was about 7 miles.

The second DARPA Grand Challenge in 2005 had a similar setup with a course defined by some 3000 waypoints over 150 miles through the desert. All finalists based their work on high-end laser scanners coupled with high-precision GPS/INS systems and radars for long range sensing. Again vehicles had to avoid static obstacles only on the closed-to-the-public course. Five teams led by the Stanford Racing Team finished the course (Darpa 2005, Thrun et al. 2006, Özgüner et al. 2007).

The third DARPA Challenge held in 2007, named *Urban Challenge*, took place in a mock up urban environment in California. A Road Net Description File was available that included a map of the terrain and the local traffic rules. Vehicles had to negotiate their way through traffic build by other participants and stunt drivers following regular traffic rules. The main sensors used by the finalists were a high-end, roof-mounted lidar scanner (Velodyne 2007),

high-precision GPS/INS and radars were used for long range sensing, while computer vision played at most a secondary role. The team of Carnegie Mellon University won before Stanford and Virginia Tech (Urmson et al. 2008).

The Grand Cooperative Driving Challenge 2011 (GCDC) was the first international competition of vehicles connected with communication devices. Participating teams from about 10 countries had to come up with strategies that were able to drive without knowing the algorithms and technical equipment of other vehicles in their platoon. Teams were shuffled to a random starting position in a random platoon over 15 runs on a highway near Helmond, the Netherlands. Criteria for performance evaluation included damping to strong oscillating braking/acceleration maneuvers of the common platoon leader, overall traveling time and platoon length of the team. The team of KIT won before Chalmers University (Geiger et al. 2012).

Inspired by the challenges, numerous research groups from industry including and academia continue research and automated driving demonstrations in increasingly complex scenarios can be expected in the near future.

In 2010 a team of Braunschweig University extended their work of the Urban Challenge by automated driving in public traffic on a piece of the Braunschweig city ring road within the Stadtpilot Project (Wille et al. 2010, Saust et al. 2011).

Among the publicly most noticed activities is the impressive work by Google that extends experience gained in the Urban Challenge. A roof-mounted high-end laser scanner and a detailed map, recorded in a prior manual drive, provide the main information about the driving environment. A color camera is used for traffic light recognition. The overwhelming amount of more than 500.000 km of automated driving has been reported in 2013 (Markoff 2013).

In July 2013 a car drove autonomously in public traffic near Parma, Italy, remarkably at times even with nobody on the driver's seat. The 13 km long route included two-way rural roads, freeways with junctions, and urban areas with pedestrian crossings, tunnels, artificial bumps, tight roundabouts, and traffic lights (PROUD 2013).

In August 2013, a collaboration of Daimler AG and KIT/FZI automated a Mercedes Benz S-Class demonstrating the maturity of mono- and binocular video sensors augmented only by serial or close-to-production radar and GPS sensors and a digital map. The vehicle successfully drove the 100 km long Bertha Benz Memorial Route from Mannheim to Pforzheim, Germany, in presence of crossing pedestrians, bicyclists, vehicles and trucks in narrow urban and rural roads and complied with traffic rules including traffic signs and lights (Franke et al. 2013, Lategahn et al. 2013, ITS Podcast 2013, Ziegler et al. 2014).

As outlined above, highway and freeway automation and low speed automated driving are currently being introduced in first products. Urban driving, however, poses a particular challenge because it involves many different situations and complex scenarios, that state-of-the-art technology is not yet able to handle and is therefore a focus of ongoing research activities. The project UR:BAN (2012–2016) (UR:BAN 2014) gathers various stakeholders for these applications to prepare a new generation of driver assistance functions (Manstetten et al. 2013).

Related Research Directions

Beyond all enthusiasm concerning technological progress, however, it must be acknowledged that automated driving in all conceivable traffic situations requires considerably more cognitive capabilities than available at the current state-of-the-art. Furthermore, clear definitions for liability, licensing, and registration of automated cars are yet to be devised. Therefore, as an interim stage, some research projects focus on so-called 'semi-automation' or 'high automatization'. Human factors play an important role in such systems that share tasks and responsibility between the human driver and the semi-automated vehicle. There are approaches favoring a human-machine cooperation in general (Hakuli et al. 2009, Kienle et al. 2009) or in dangerous situations, see, e.g. the research project HAVEit (2007–2010) (HAVEit 2010). In other approaches, the machine takes control whenever the driver is unable to, and automatically halts the vehicle or pilots it to a safe position, as demonstrated in the SmartSenior project (2009–2012) (Kämpchen et al. 2010).

Until full automation is feasible, support of the driver by DAS is sought. They can intervene in case of deficient driving abilities, when, for example, the driver becomes drowsy. Drowsiness detection and warning systems are already on the market. Based, for example, on drivers' steering behavior and response times, length of the trip, use of turn signals, and time of day (Bosch 2012), the system alerts its users of possible drowsiness. Effects and consequences of drowsiness detection, especially in terms of acceptance by the driver, are, however, not yet profoundly researched. Aside from drowsiness, inattention can also occur when the driver neglects his primary driving task due to distraction by an auxiliary task. Interior cameras can recognize this state and adapt the parameters of warning and intervention systems (Trivedi et al. 2007).

Distraction aside, it is possible that the driver is unable to handle all incoming information and act upon it correctly, even when allocating full attention to the primary driving task. As this especially pertains to night driving situations, systems to enhance night vision have been developed. One such technology uses "intelligent headlights" (Thom et al. 2011). This technology allows illumination of specific solid angles to maximize the illumination of the road without dazzling other traffic participants. Furthermore, areas of high relevance can be illuminated for a short time to attract the driver's attention. Other night vision systems are based on close-range and long-range infrared technology, providing an on-screen display of the

driver's surroundings. Recognized objects, such as pedestrians, can be highlighted, or trigger an active warning (Horter et al. 2009, Li et al. 2012).

Mental over- or underload due to the varying complexity of traffic situations can be another source of erroneous driver behavior. Though researchers have presented assistance concepts based on mental load (e.g. Smiley 1989), no proper implementation of such a concept into the human-machine-interaction has yet been realized. At best, simple attempts to avoid mental overload from complex traffic routing have been made with assistants indicating the number of lanes and the traffic situation on the upcoming road. Mental underload from monotony, with the potential to induce inattention (e.g. Young & Stanton 2002), is an entirely unresolved issue. An attention deficit may manifest far before the driver enters a state of drowsiness that could be picked up on by drowsiness detection systems. Solutions for the problems posed by mental over- and underload could contribute greatly to the improvement of DAS.

Apart from a general lack of market penetration, it is known that DASs are not well distributed in accordance with the needs of specific user groups. As can be seen from Fig. 2, the groups with the highest probability of being the main perpetrator of an accident are young and old drivers (Destatis 2013). The prevalence of DAS as of today, however, appears limited to a small user group of mostly middle-aged persons (Langwieder et al. 2012). Use of these systems is often impeded by the inability to be retrofitted in one's current vehicle (Trübswetter & Bengler 2013).

Soon after DAS became available for passenger cars, they were also offered in commercial vehicles. Due to the universal ambition to save costs, such systems were, however, even less frequently acquired in this sector. Unlike in the private sector, regulations (EC No 661/2009) were put into place, making it a legal requirement for certain commercial vehicles to come equipped with, for example, emergency braking and lane keeping systems as a serial standard.

Other than traffic jam prevention, through ACC (van Arem et al. 2006), assistance systems have not yet been able to contribute much to traffic efficiency. To achieve a noticeable improvement, assistance systems need to extend their capabilities towards cooperative driving. Though previous research has shown that cooperative systems can improve efficiency (e.g. convoy driving (Schulze 1997)), an underlying functional concept of cooperation has not yet been established. In terms of energy efficiency, existing possibilities to increase efficiency are not yet being broadly applied. To date, cooperative driving exercises of different vehicle groups, for example, were only rudimentarily examined (Frese et al. 2007).

In an intermediate conclusion, one may summarize that automotive research and engineering offers a broad inventory of DAS with a potential to improve the quality of mobility. In the long term, cooperative automated vehicles can be expected from this technical evolution. Today's market situation of DAS, however, suffers from the following yet unresolved weaknesses:

▪ Even when available in the class of compact cars, DAS are ordered only by a minority of customers (Karmasin 2008, Krüger 2008).
▪ Overall, DAS acceptance is increasing but are often poorly understood by users (Zwerschke, 2006).
  ▪ DASs are unattainable for relevant social groups and cannot be upgraded or retrofitted.
  ▪ DASs communicate with the carrier vehicle only, and remain isolated from other road users and traffic infrastructure. They have not yet found their way into intermodal traffic (Saust et al. 2012).

This non-exhaustive list discloses the foci of future developments. DAS need to be embedded into transportation systems on a larger scale. They need to be interlinked with one another, between different users, and to other technical systems.
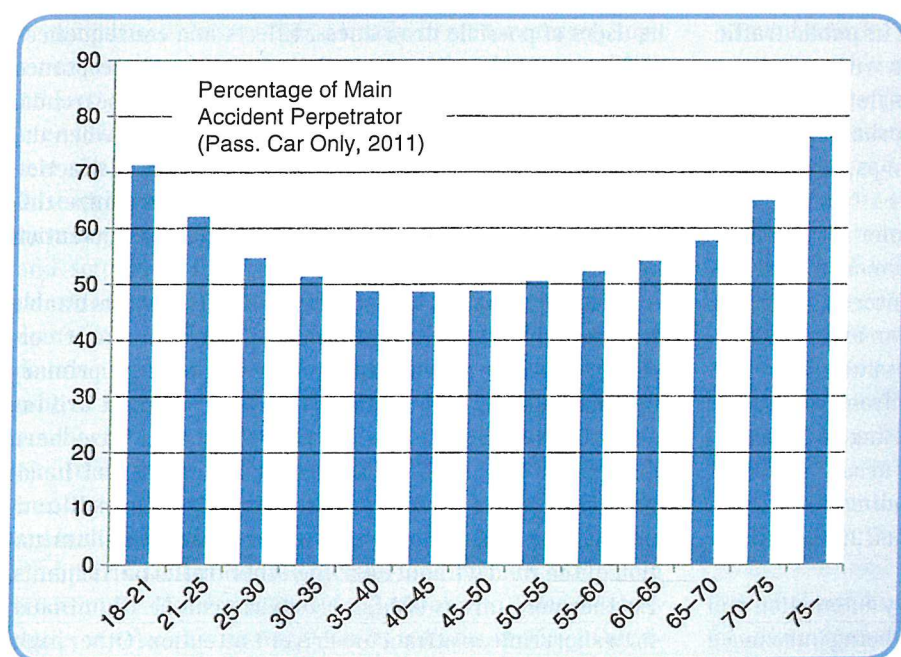
3. Stimuli for Future Developments
In addition to several essential technological breakthroughs in the past, further leaps in technology are expected in the future. A vehicle's awareness of its surrounding environment is

FIG 2 Share of being the main perpetrator of accidents with injuries for age group involved (Destatis 2012).

becoming increasingly complete and more detailed, especially with innovations such as new image processing approaches with 6-D (e.g. Müller et al. 2011, Rabe et al. 2010, Rabe et al. 2007), imaging radar systems (Köhler et al. 2013), and improved positioning systems. Through advancements in hardware and software, a relatively high level of artificial intelligence is likely to be established. Machine cognition will continually improve, ultimately paving the way for fully autonomous driving. As a long term development, an increase in efficient and smooth traffic flow with few accidents is to be expected. However, before this vision can become a reality, a number of issues have to be resolved.

Car2Car and Car2X Communication

The internet, has, so far, played an only marginal role in vehicles. Up until now, the use of data links has been restricted mainly to infotainment and navigation support. In the future, along with developments in the infotainment area, new driving assistance capabilities can be expected. The "driving office" is certainly an interesting concept for managers and businessmen. It may be assumed that, in the future, the mobile office and autonomous driving package will be subject to intense request in regard to company cars. Other potential use cases for data communication include the allocation of parking spaces before the actual arrival of the vehicle at the parking lot, or the communication in intermodal traffic.

Communication-based DAS for guidance or stabilization support on the other hand require an independent network concept. In field operational tests, like SIM-TD (www.simtd.org) and research projects like Ko-FAS (www.kofas.de) and Koline (Saust et al. 2012), the foundations for a comprehensive implementation of such technology are being laid down. Integrating all traffic participants of a certain area into a common network, a new stage of driving assistance can be realized, based on the vastly improved quality and quantity of information about the local traffic situation. This would, for example, impact traffic infrastructure considerably (Tank & Linnartz 1997, Tischler & Hummel 2005, Nagel et al. 2007, Dietl et al. 2001, Eichler 2007, Kosch 2004). A traffic light, for example, could be replaced by a wireless access point that directs the vehicles through the junction. While this approach would be more efficient and effective with automated vehicles than with human operators, it should yield positive results irrespective of who is driving the vehicle. Vehicles equipped with sensors and v2v communication devices could expand their horizon via cooperative sensing. Given sufficient bandwidth and integrity of the data sources and the communication network, information from all the vehicles and the infrastructure, if available, could then be fused into a detailed dynamic map, as demonstrated in the EU project DRIVE C2X (www.drive-c2x.eu). In analogy to the IT-cloud concept, shared sensor data could be described as cloud-sensors.

As depicted in the traffic scenario in Fig. 3, vehicles may communicate slowdowns to their rear or inform forward traffic about the presence of vehicles in their blind spot. Furthermore, connected vehicles may negotiate driving trajectories to their mutual benefit and to the benefit of overall traffic flow and safety (Stiller et al. 2007, Goldhammer et al. 2012).

Seeing the enormous potential to increase driving safety and efficiency with respect to energy, time and traffic infrastructure, such networks will hopefully soon become a reality for the benefit of all traffic participants (European Union 2010). The high initial costs associated with the provision of a sensor-cloud concept can be expected to be redeemed during long term usage. A necessary precondition, however, is a reliable network with a high quality of service and integrity, which is yet to be developed.

Electro-Mobility

Electro-mobility, too, presents new challenges for driver assistance. Primary requisites are an adequately tight network of charging stations and guaranteeing a sufficient amount of energy to complete the desired journey. For example in March 2014, Tesla has 66 stations in the US, which can only be seen as a starting point (Tesla 2014). In the course of these issues being resolved, the usage of e-mobility can be expected to change. This will mainly affect variables of energy efficiency, forcing a series of decisions on the means and the objectives of mobility in general, as well as on business models to be implemented in light of the respective technological state-of-the-art. Accordingly, assistance functions will have to adapt to altered basic conditions of transportation usage and provide additional functions for intermodal mobile assistants and range extension.

One approach towards improved energy efficiency, discussed particularly often in the e-mobility sector, is the
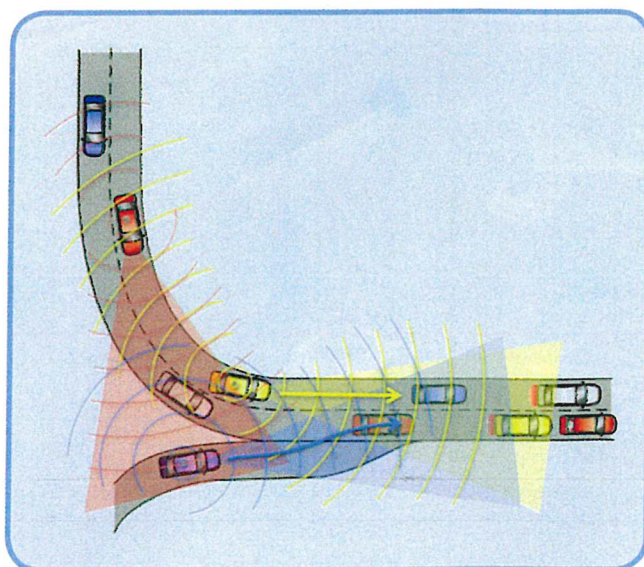

FIG 3 Cooperative traffic of communicating vehicles.

reduction of vehicle weight. Besides the weight of the engine and the transmission a high proportion of a vehicle's mass is attributed to passive passenger safety. Increasing the emphasis on and improving the performance of active and integrated safety systems can thus pave the way to a significant reduction of vehicle weight.

Societal Changes and Market Trends

Changes in society will reflect in changes of technology. In regards to mobility, two major trends of societal change can currently be observed. One manifests in the world of senior citizens. Being the first generation of elderly people having used individual mobility for a large part of their lives, they have grown accustomed to and wish to maintain their acquired standard of mobility. Several factors, like extended retirement ages and changes in family structure, can even make this a necessity. The need to adapt to the specific needs of the elderly becomes apparent. Moreover, the trend reminds us, that, while hard to imagine today, there will be future generations accustomed to technology like "the cloud", demanding intelligent vehicles with high support for driving tasks. Another major societal change regarding

mobility occurs within the young generation. Having grown up with a high degree of individual mobility as a common standard, they tend to take mobility for granted. In conjunction with increasing urbanization the car as an important symbol of societal status is being replaced by other values, such as real estate, group affiliation, or design icons. The consequences of this trend are not yet clear. It could lead to the possession of a vehicle becoming increasingly less important in the course of increasingly rational choice of transport. Or it could promote an increasing emphasis on design features in a car to help it regain its function as a symbol of societal status. As with the "iPhone" in the mobile phone sector, interaction concepts that differ radically from established standards are often key to product success, with competitors quickly following suit, thus rendering previous, conventional product generations hard to market. In vehicle design, this could cause the steering wheel and pedal interaction concepts, developed more than 110 years ago, to be abandoned (see e.g. Fig. 4). In the course of such a reinvention of driver-vehicle-interaction, new elements like assistance functions and partial automation could find their way into the proverbial "iCar" not as an optional feature, but an integral and defining part. Provided such vehicles share the success of today's models, conventional vehicles could quickly become "old" rather than "classic".

A different market trend results from changes in the value-creation chain. Companies generate revenues by brokering product deliveries. The Apple App Store, for example, provides a distribution platform as its own investment, but does not take over the risk of product development and warranty obligation. These business models have not yet been applied to the mobility sector in large scale. Currently, there is only a small number of successful mobility platforms like organized ridesharing or used car portals. Smartphone based approaches, such as the App "taxi.eu" (www.taxi.eu) , demonstrate how the product mobility can turn into a brokered good. Such services can prove to be an obstacle or a catalyst for the further development of DAS. In vehicles optimized for cost reduction, requirements are likely to be fulfilled with minimal effort in the least expensive way possible, which could prove fatal for the budget for innovations. On the flip side, certain automation technologies, for example driving to a parking lot, the next customer, or even a mobile ordering office for an online retailing corporation, can serve as the technical basis for future business models (Bläser et al. 2012, Terporten et al. 2012).

The Role of Culture and Media

Other stimuli for future developments can come from the adaptation of traditions or new developments from other

FIG 4 Drive-by-wire-system (Daimler Media Services).

cultures. Increased globalization accelerates the rate of such transfer. Regarding market and technology, German and Japanese companies currently dominate the driving assistance scene; this is primarily due to the customers and automobile companies being sufficiently willing and financially strong to invest in vehicle technology. As time passes, older, more saturated markets may be overtaken by newer, emerging ones. This results in a change of numbers, customer needs, and usage conditions, as well as the initial difficulty to appraise willingness to pay and foresee possible regulative interventions.

Finally the role of media should not be underestimated. It is obvious that the presentation of Google's self-driving car in the media has both changed the attitudes of users and the effort of established car manufacturers with respect to this technology.

4. Challenges and Effects

For future transportation technology, simple roadmaps showing different developmental steps can be derived. Usually, these plans culminate in an interconnected autonomous vehicle, able to drive unsupervised in any possible environment. Along the paths towards such a vehicle, many arduous issues of homologation and liability have to be addressed. Today's testing and approval methods are unsuitable for the evaluation of intelligent machines, and new metrics assessing the performance of driving robots are required. Some experts consider this an even greater challenge, than the development of artificial intelligence for autonomous driving itself. The U.S. National Highway Traffic Safety Administration (NHTSA) for example, though explicitly encouraging the development and testing of self-driving vehicles, has recently published the specific recommendation for state governments to not even attempt to establish safety standards for such technologies at this point in time (NHTSA 2013).

Another aspect impeding advancements are their costs. Technological development requires large investments that can only be redeemed by an appropriate market demand. If the market does not accept the developed product, financing further developmental steps may prove difficult. This risk is increased by several mediating influences on a product's way from its development to its end user. So-called specialist magazines often prefer to rave over the sound and power of a combustion engine instead of covering meaningful technological innovations in an appropriate manner. Even trade chains and car salesmen often fail to promote the technology properly. It is worth pointing out, however, that development of DAS has not always been user-oriented and is therefore, in part, co-responsible for low user acceptance (Maurer 2012). In order to maximize the success of human-machine-interaction, the increasing number of assistance functions requires the development of integrated display and control concepts, providing a consistent user interface.

Technological development is also impacted, as has been discussed, by social changes. Market response to changed conditions can result in a product line shift or entirely new business models, creating new markets and suppressing old ones. Such revolutionary market changes may prove especially challenging for the well-established German automotive industry. The example of the IT sector (dominated by companies like IBM/DEC/Nixdorf, then Microsoft/Intel/Nokia, then Google/Apple/Facebook) demonstrates that decades of success are transient if circumstances and business models change.

DAS appearing at the right time and along with a fitting business model can be a key element to revolutionize individual mobility. As long as cars are used the way they are today, the market is not expected to change remarkably. But the development of DAS, especially towards autonomous vehicles, opens up different usage options. This progress cannot be held back and potentially threatens today's dominant car companies, if they fail to pro-actively be part of it. In order to help co-create the future, extensive scientific research is required to prevent misdevelopments, find optimal terms of implementation, and observe the market.

While future DAS are expected to contribute greatly to traffic safety and efficiency, they are also likely to entail side-effects. Depending on the pace at which new assistance systems are implemented, a segregation of high-tech assisted automobiles and still operable older vehicle models may occur to an extent surpassing the already given situation. While such conditions could act as an incentive to buy a new model, they could as well exacerbate discrimination and envy between vehicle holders. Since any market change will produce winners and losers, an impact assessment of technological innovations should be conducted beforehand, to ensure that technological progress does not get stifled and that its advantages are made visible.

Since they are a vision of the distant future, the effects of interconnected autonomous vehicles cannot yet be fully estimated. Traffic flow and traffic safety will increase, while "old" vehicles could be considered a traffic obstacle or safety risk. Here, a legal obligation to new technology may be worth discussing. On the plus side, the need for parking space close to a destination would become less relevant, as vehicles could drive to and from any external parking space by themselves; this would additionally benefit the environment, reducing the amount of land required to build parking lots. Transportation centrals could work as bookable resources managed within a network, which would create new opportunities for the industry as well as public authorities.

Even though it is difficult to transfer from one technology to another, the new quality of mobility gained by autonomous vehicles could change our lives in the next 20 years as it was the case with mobile communication. The preconditions from a research point of view are presented in chapter 5.

5. Future Research Foci

Despite all previous successes of driving assistance research and development, much can still be achieved. Four focus areas have been established from the technical perspective.

Individualization

One important focal point emerging from the status quo is the need for individualization of DAS functional parameters and HMI, the need to adapt to individual preferences and requirements. On the one hand, this implies paying special attention to and developing DAS specifically for particular user groups. This need becomes apparent in regard to elderly drivers who need to preserve their individual mobility for as long as possible, but is equally applicable to young drivers who are disproportionally frequently involved in accidents, motor bike drivers as users of a vehicle-class inherently different from four-wheelers, and commercial bus and truck conductors with their unusually high driving frequencies and heavy vehicles. Regarding the latter, traffic safety should
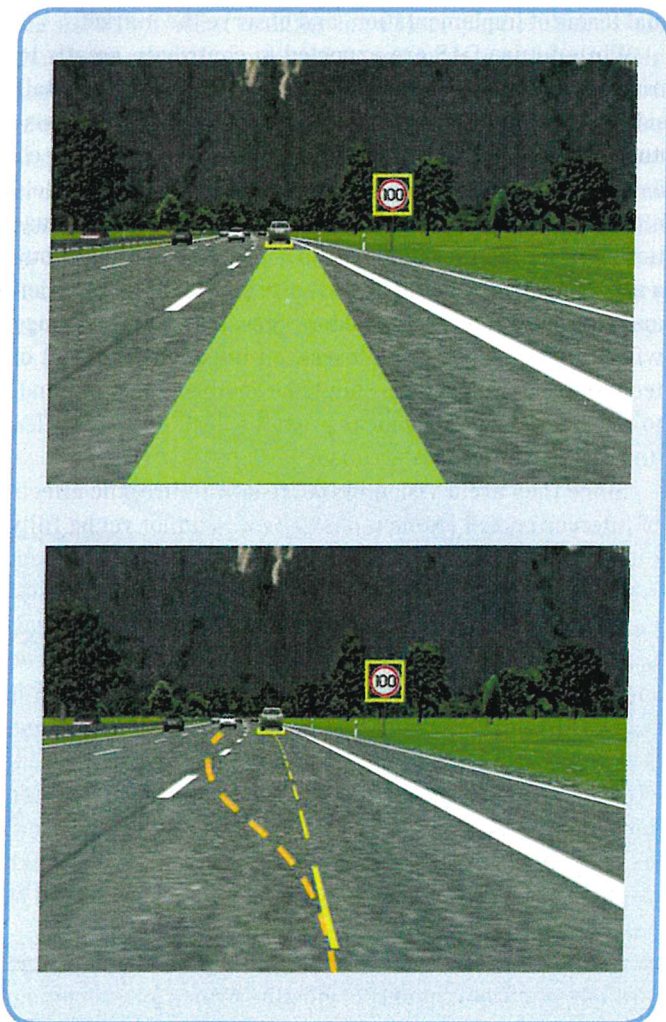

FIG 5 Visualization of intentions (potential trajectories and speed limits) of a highly automated vehicle in a contact-analogue head up display (Damböck et al. 2012b).

be re-evaluated after the introduction of the new emergency braking and lane keeping systems, in order to determine what additional support is required.

On the other hand, the need for individualization and adapting to user preferences and requirements also implies optimizing the human-machine-interaction. By reducing deficits of existing functions in this context, quality of experience and transparency of the system for the user could improve user acceptance and promote market penetration. Especially the increase of different DAS functionalities that clearly exceed classical ACC and lane keeping support makes integrative interaction concepts necessary. Integration of the presentation of information of e.g. all longitudinal support systems or lateral support systems is thinkable. Free programmable displays plus head up displays and haptical feedback are promising enabling technologies for this. Additionally integration is reasonable in the area of driver input as an increasing number of buttons and controls needs to be located in the interieur for different functionalities. Function development focused on individual usage and optimal parameterization become particularly vital for future assistance functions, especially in highly-automated vehicles (Kienle et al. 2009). It is important that new interface technologies for displays and controls provide high immersion of the driver into the driver-vehicle-system to ensure the system is—figuratively—controlled by the driver's intentions, and that task sharing between driver and automated functions is intuitive and reliable (see. Fig 5 for a contact-analogue head up display). All stages towards a fully automated vehicle require fail-safe interaction concepts for a handover of responsibility between driver and vehicle. Since such progress can be achieved only via commercial success, the systems require a high hedonic quality regarding all aspects of the interface's design (Krüger 2008). For both, market success as well as traffic safety, individualization is imperative and should be tackled internationally in order to meet requirements for different societies, economic zones, and jurisdictions.

Future Foci

- Assistance functions addressing specific requirements of specific user groups, especially young or elderly drivers as well as motorcyclists
- Analysis of traffic accidents after introduction of emergency braking and lane keeping support systems
- New human machine interfaces to support immersion into an integrated driver-vehicle-system
- Driver intention recognition
- Concepts for cooperation between driver and vehicle in automated mode
- Raise hedonic quality in regard to acceptance and market success
- International approach to DAS to achieve acceptance in different countries and cultures.

Machine Perception and Cognition

Today's sensors are capable of collecting detailed data of a car's surrounding environment, but machine cognition and situational awareness are still in their infancy. To improve them, significant progress is required in symbolic scene classification, e.g. object recognition under dynamic conditions, as well as in contextual scene understanding, e.g. inference of the relationship between different dynamic objects and with traffic infrastructure elements (Fig. 6). Last but not least, the uncertainty and vagueness of the information from and interpretation of the traffic scene needs to be made explicit.

Managing the above is crucial for the realization of appropriate driving functions and corrective actions in complex traffic situations. The acquisition of information should be based on more sources than are available in today's cars. High precision ego-localization in rich 3D digital maps will play a special role (Nothdurft et al. 2011). New hardware concepts and algorithms for sensor data acquisition and interpretation could pave the way for performance improvements at reduced costs. Machine vision techniques for image sequence analysis as well as microwave and active optical sensor technologies, still exhibit large potentials to enhance spatio-temporal resolution and situational awareness of the perceived traffic scene. Methods for scene representation, including measures for quality, need to be further elaborated as a basis for situational awareness.

Another future focus will be on a probabilistic prediction of likely future behavior of the ego-vehicle and other traffic participants, based on comprehensive intention inference and behavior modeling (Liebner et al. 2013). Figure 7 shows an example for ego-vehicle path prediction including based on machine learning algorithms (Wiest et al. 2012).

Future Foci

- Improved algorithms for vehicle situational awareness in complex traffic scenarios, especially in urban environment
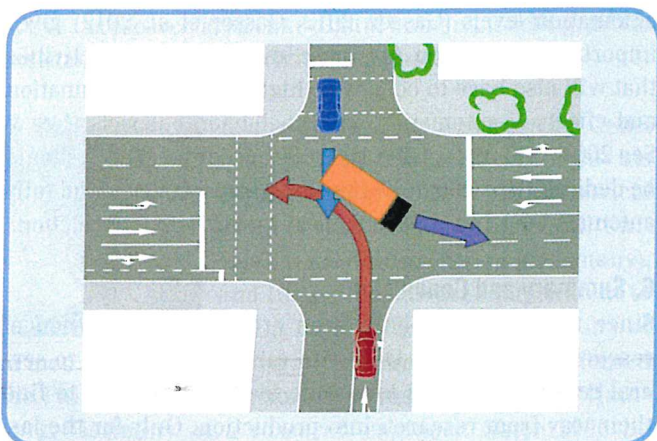- Improvement of sensor hardware and software to yield richer high-quality information
- Development of methods and algorithms to acquire situational awareness at a safety-relevant integrity level
- Automated generation, updating, and distribution of local dynamic maps
- Intention and behavior models to predict the behavior of the driver and other traffic participants.

Methods of Assessment

In the past, driving assistance research focused on technological breakthroughs. The emphasis is now shifting, as methods of assessment (e.g. Fecher et al. 2008, Schöner et al. 2011, Aparicio et al. 2012, Brahmi et al. 2013) become increasingly important. Without suitable and generally accepted methods of assessment, potentially distracting or unsafe functions cannot be introduced to the market.

Conventional testing procedures are insufficient to ensure the safety of increasingly complex future assistance functions involving machine perception and cognition. For this reason, only apparently "harmless" assistance functions, like ACC or systems with short intervention periods like emergency braking assistance, are currently available. However, the number of DAS and their functional range are expected to grow considerably in the near term. If testing and assessment methods cannot keep pace with this functional growth, they will become the bottleneck of the introduction of advanced DAS to the market (Maurer & Winner 2013).

Currently, all stages of DAS development lack economically feasible concepts for assessment (Winner & Wolf 2009). These include the evaluation of machine perception (Brahmi et al. 2013), the assessment of desired as well as faulty function behavior, and last not least, user acceptance tests. A particular challenge is posed by functions that delegate decisions from the human operator to the machine in unexpected scenarios. In these cases, market introduction requires prior proof that the risk taken on by handing vehicle control over to the machine is at most equal to the risk taken on when the human driver is in control (Färber & Maurer 2005, Bock

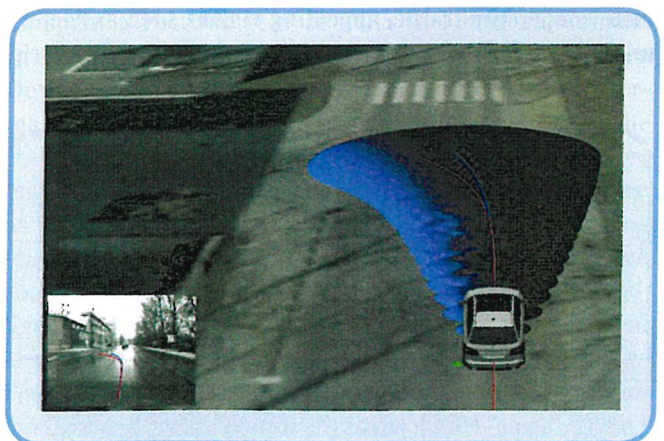FIG 6 Improving machine cognition and situational awareness are future challenges.

FIG 7 Ego-vehicle trajectory prediction using the trajectory history and present sensor signals like steering angle and yaw rate.

et al. 2007). Two yet unresolved issues arise: how to measure performance of the machine and that of the human operator (Damböck et al. 2012a). Valid assessment methodologies exist for neither, not even to mention the case of shared or cooperative control by human operator and machine (Bengler et al. 2012). To allow comparison between different control modes, a suitable metric has to be devised.

Since a solution to these challenges is not to be expected in near term, research on suitable assessment methods constitutes a part of the critical path to be taken in order to avoid DAS development being held up for decades.

Future Foci
- Testing and evaluation methods for machine cognition and (semi-) automated assistance functions.
- Concepts for the assessment of human and machine driving performance.

Cooperative Driving
The fourth focal point concerns the interconnection of and the cooperation between individual vehicles in order to establish a traffic network. Existing communication networks and in particular near-future vehicle2x networks open up a wide spectrum of improvements to the holistic performance of transportation systems. Hence, existing approaches should be further developed towards a level of maturity that allows market introduction and increases the safety of all traffic participants through the benefits of shared information (Fig. 8).

Initially, driver assistance functions based on vehicle2x communication will have to provide benefits even with low market penetration rates. In the long term, high penetration can be expected, requiring additional concepts to be established in order to further optimize traffic, including minimizing resource consumption and maximizing safety. These concepts should furthermore not focus merely on individual rides, but also provide interfaces to currently inactive or intermodal traffic in order to interlink alternative transportation systems. When DAS are modified to promote cooperative traffic, appealing visions such as "deterministic traffic" can come true. This would mean that a trip

FIG 8 Information sharing using Car2x communication circumvents dangerous situations.

is carried out according to an interactive schedule with traffic participants moving in imaginary spatio-temporal slots.

Future Foci
- Incorporation of vehicle2x networks for the sake of traffic safety and efficiency.
- Collective provision of accurate local traffic information.
- Collective traffic control based on individually operated cooperative systems.
- Continual joint mission planning with reliable prediction of the individual vehicle trajectories.
- Usage optimization of deterministic traffic system concepts.

Social Foci of Research
The foci addressed so far concentrated on research areas from a technological point of view. They are based on the expertise of the authors of this technical report. However, not all relevant topics have been exhaustively addressed. DAS not only reflect the progress of technology, but are developed for humans who purchase and use them; they make a difference for individual and collective safety as well as for the mobility of groups and individuals.

Development of advanced DAS may be stimulated by market acceptance or stunted by societal reservations (Krüger 2008, Karmasin 2008). On the other hand DAS - particularly those with a high degree of vehicle automation - may induce changes in traffic behavior (Freyer 2007 et al., Freyer 2008). Furthermore, advanced DAS may stimulate new business models and have a drastic impact on the nature of future mobility. An early pro-active assessment of the consequences of technology may reduce potential conflicts. Here, political and social discussions can begin prior to market introduction, thus reducing the risk of investments loss (Homann 2005). A crucial input for this discussion will be reliable and valid methods to assess the controllability of DAS. This assessment has not only to focus single functions as addressed in the RESPONSE Code of Practice (Donner et al. 2007) but moreover the combination of functions in increasingly complex scenarios. The BASt taxonomy of automation levels (Gasser, 2012, Gasser et al. 2012) gives important orientation for these methodological activities that will also have to cope with higher levels of automation and effects of automation under behavioral aspects (Lee & See 2004). Finally, further interdisciplinary research should be dedicated to determine the social impact of DAS and fully automated driving to pave the way towards its introduction.

6. Summary and Conclusion
Since the 1980s, we have seen a long-term evolution of research in advanced DAS with different foci. Due to several reasons, it took a long time for these systems to find their way from research into production. Only for the last few years we could observe an increasing, significant market penetration of DAS. In the course of the next several
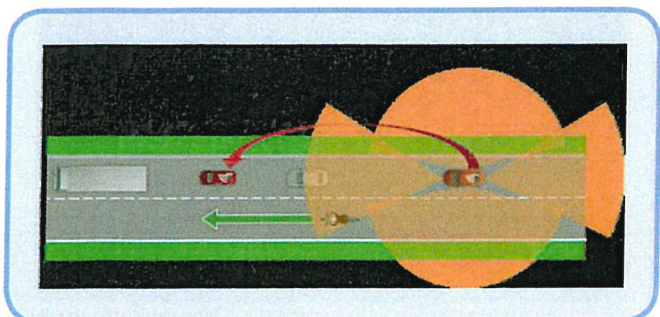
years, this will be further boosted by the new regulations of the Euro NCAP (NCAP 2014), where the maximum score of five stars will only be awarded to cars equipped with basic DAS. But users themselves are also beginning to see the advantages of such systems and are becoming increasingly willing to pay their price.

Currently, we are observing the trend that previously isolated driver assistant functions are merged together, in order to realize more complex assistance with respect to both, longitudinal and lateral, driving support. Partly autonomous driving is expected to become a reality within the next few innovation cycles of high-end cars, and even highly automated driving no longer appears completely out of reach.

Before such progress can be achieved, however, not only a suitable regulatory framework must be adopted, but significant research is required. The main topics, of course, are technological, such as improved machine vision and situational assessment. This includes the mapping of learned driving experience of human operators to machine cognition. On the other hand, soft factors, e.g. the acceptance of such systems by its end users, should not be neglected. This obviously requires functional transparency and reliability with respect to autonomous behavior, along with adequate HMI concepts. These inter-disciplinary challenges can only be overcome by a close collaboration between engineers and psychologists. All of these aspects demand a significant amount of fundamental research for at least the next decade.

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Klaus Bengler graduated in psychology at the University of Regensburg in 1991 and received his Doctorate in 1994 in cooperation with BMW. After his time in BMW Research and Technology responsible for HMI research and usability he is now leading the chair of Ergonomics at Technische Universität München which is active in research areas like digital human modeling, driver assistance, automated driving and human reliability.

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Hermann Winner began working at Robert Bosch GmbH in 1987, after receiving his Ph.D. in physics, focusing on the pre-development of "by-wire" technology and Adaptive Cruise Control (ACC). Beginning in 1995, he led the series development of ACC up to the start of production. Since 2002, he has been pursuing the research of driver assistance systems and other automotive systems engineering topics as professor of Automotive Engineering at the Technische Universität Darmstadt.

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