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Connected Car: technologies, issues, future trends

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The connected car -a vehicle capable of accessing to the Internet, of communicating with smart devices as well as other cars and road infrastructures, and of collecting real-time data from multiple sources- is likely to play a fundamental role in the foreseeable Internet Of Things. In a context ruled by very strong competitive forces, a significant amount of car manufacturers and software and hardware developers have already embraced the challenge of providing innovative solutions for new generation vehicles. Today's cars are asked to relieve drivers from the most stressful operations needed for driving, providing them with interesting and updated entertainment functions. In the meantime, they have to comply to the increasingly stringent standards about safety and reliability. The aim of this paper is to provide an overview of the possibilities offered by connected functionalities on cars and the associated technological issues and problems, as well as to enumerate the currently available hardware and software solutions and their main features.

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1. INTRODUCTION

The automobile market has been pushed for refinement and for further upgrades for more than a century, with each scientific discovery providing new attractive alternatives for cars to be equipped with. It has been more than thirty years since the first introduction of small software components in cars; then, a vast amount of different services has started to build on new enabling technologies, creating a babel of architectures, platforms and programs.

The relevance of innovative software components stands out when one considers that cars are among the most widespread goods of all time (the amount of registered cars in the world is just below one billion, as pointed out in [Gharavi et al. 2007]) and that people, typically, are inside their vehicles for a considerable portion of their days [Perera and Dias 2011]. Furthermore, the individual needs and desires of each customer can vary significantly, and they must not be neglected by functionality providers.

Original electronic equipment for cars consisted of a small number of ECUs (i.e. Electronic Control Units), each one totally uncoupled from the others and dedicated to an individual simple function. Thanks to progresses in electronic technologies, interconnection and exchange of data between ECUs has been made possible, and so it has been for the development and deployment of very sophisticated communication architectures between them [Broy et al. 2007]. Today, as it has also been pointed out in [Greengard 2015], the electronic equipment of a car can consist of up to 70 ECUs connected to five system buses, running about 100MB of binary code (which means tens of millions of lines of code - note that it is slightly more than the lines needed for MAC OS X "Tiger", and about ten times the amount of code written for a Boeing 737 airplane [Daily Infographic 2013]). Next-gen cars are expected to push the boundaries further, running up to gigabytes of software. In figure 1 some examples of ECUs (including those actually pertaining infotainment functions) mounted on today's cars are shown. The great variety of functions they offer is evident.

By the Nineties, protocols extending the 802.11 wireless standard appeared to enable communications between different vehicles moving on the road, and between vehicles and pieces of intelligent road infrastructure. Meanwhile, more and more sophisticated functions were provided by dashboards, with a consistent deployment of GPS functionalities on luxury cars. These technologies laid the foundation for the concept

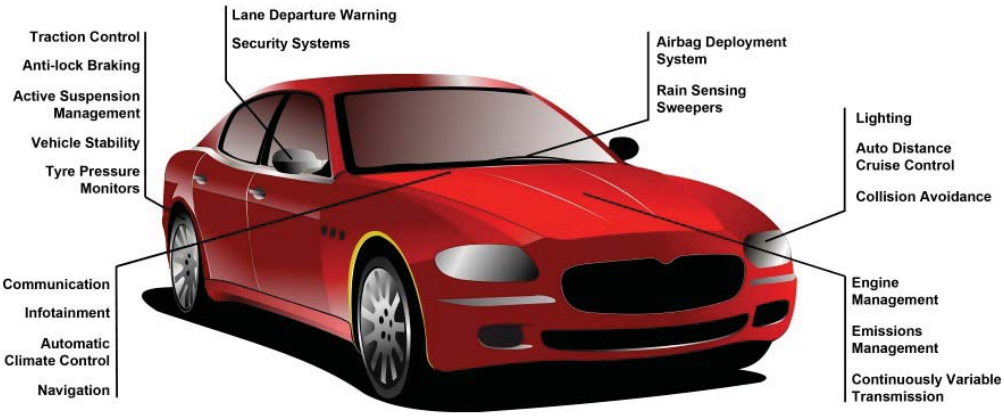


Fig. 1. Some examples of ECUs installed on today's cars. (Vector Graphic Source: http://www.WebDesignHot.com)

of Intelligent Transportation Systems, in which cars are seen as moving nodes whose position can be tracked in order to perform traffic management operations.

More recently, it has been of interest the possibility of enabling a communication between the cars and the Internet, in order to access a variety of data sources, and to provide advanced multimedia and infotainment services (more interesting than the traditional navigation and radio functionalities provided by dashboards) to the driver and passengers [Auto Connected Car News 2015]. With the recent diffusion of smartphones and similar families of connected devices, efforts have been made to integrate them with in-car dashboards, with a set of different solutions available to do so. In this way, the data collected by internal car sensors can be integrated with information gathered from the web and the surroundings, allowing drivers to have a cleaner, more secure and more proficient time spent on their driving seats [Summer 2015]. A recent survey [Viereckl et al. 2015] has highlighted the services that are demanded the most by car owners: users have an higher willingness to pay for mobility information (i.e. navigation) and infotainment, than for vehicle information (i.e. car diagnostics) and Internet. In a report from Business Insider (see figure 2), it is estimated that by 2020 75% of cars will be built with the necessary hardware to connect to the Internet.

A milestone for the beginning of the current conception of infotainment on cars can be individuated in the deployment of SYNC by Ford. SYNC is a core software platform for in-vehicle communications and entertainment, that came factory-installed on vehicles. It was originally developed on the basis of Windows Embedded Automotive, and used by Ford and third-party developers to build infotainment systems. SYNC focused on providing access to other devices, making infotainment technology available on a vast array of different vehicles [Ghangurde 2011]. The work done by Ford was then carried on by other competitors (and by Ford itself, who released AppLink in 2010), each one creating its customized connected car infrastructures. Autos are starting to be constantly gathering information from the web, the interiors and the surroundings, allowing drivers to have a cleaner, more secure and more proficient time spent on their driving seats [Summer 2015]. Since almost all consumers of the current era carry smartphones and want them to communicate with the car they are sitting in, ad-hoc systems are being developed to allow useful interactions with brought-in devices, with Apple and Android (among others) finding a new battleground for their competitive products and philosophies.

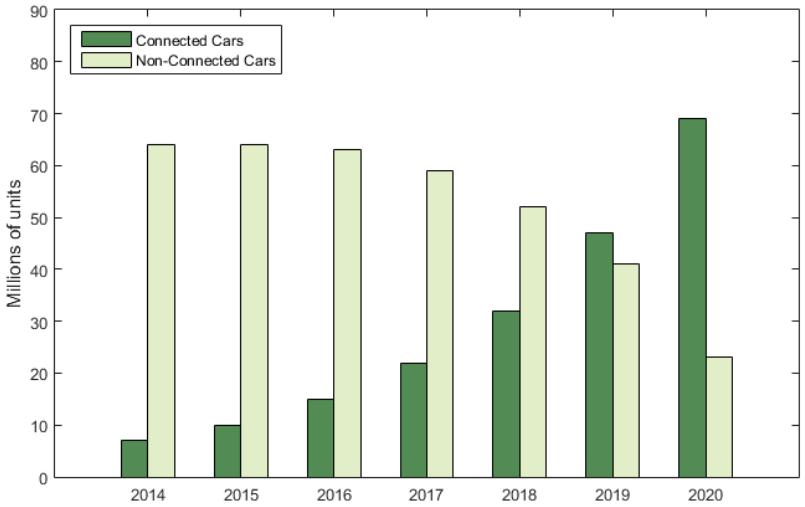


Fig. 2. Estimates about the shippings of connected and non-connected cars (Data: Scotiabank, BI Intelligence Estimates)

1.1. Definitions of connected car

Modern cars are equipped with several types of connections, either internal (the bus systems connecting sensors and computers on board, for instance) or external (the protocols enabling communications between moving vehicles). Therefore, different definitions have been given in recent times for a "connected" car, each one highlighting a subset of elements of the complete picture.

Earlier formalizations have posed their main focus on the pervasive presence of software controlling the car, with in-vehicle wireless networks connecting a large amount of electronic components. Others included elements from the outside in the connected car domain, considering services provided from automotive companies. According to [Kleberger et al. 2011], for instance, "the connected car consists of three domains: the vehicle itself, consisting of the in-vehicle network and the ECUs, the portal at the automotive company, and the communication link between them".

More accurate definitions include all other connections a modern car is equipped with: according to the American Department of Transportation, "Connected vehicle applications provide connectivity among vehicles to enable crash prevention, between vehicles and the infrastructure to enable safety, mobility and environmental benefits; among vehicles, infrastructure, and wireless devices to provide continuous real-time connectivity to all system users"[US Department of Transportation 2015]. It is worth to emphasize that, in this case, general networking capabilities are considered, not indispensably a connection to the Internet.

However, the most recent literature considers the constant connection to the Internet, and the presence of Internet-related services on the in-car dashboard, as essential elements of the connected car. With the growing diffusion of smartphones and wearable devices, the connection with them has also gained importance. Therefore, the connected car can be seen as "a vehicle that provides Internet access to all the mobile devices used by the driver and passengers. It accesses the Internet via cellular or satellite communications and provides tablet-sized screens for passengers or a Wi-Fi hotspot for passengers' own devices"[PC Magazine]. An even more concise definition, given at the 2013 Automotive News World Congress by IBM, identifies a connected

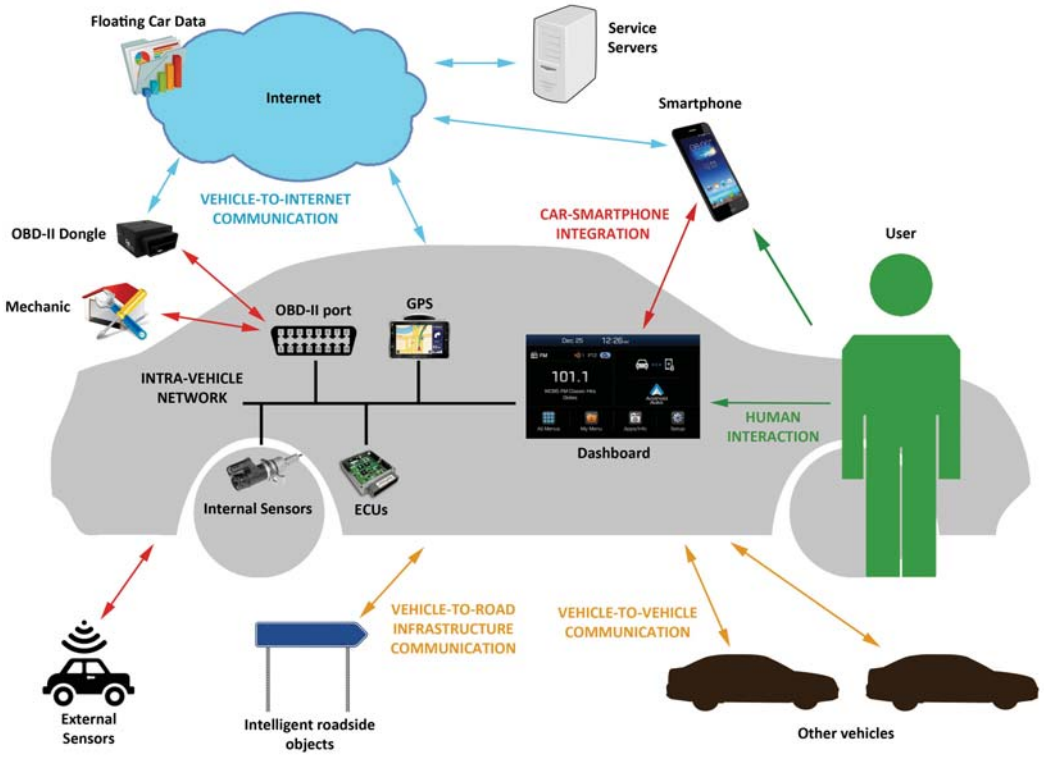


Fig. 3. Overview of the Connected Car System.

car as "a vehicle capable of seamless integration with multiple systems, connecting consumers to the digital world" [Brookes and Pagani 2014].

In this paper, we will use the following definition of connected car:

> "A connected car is a vehicle
> — capable of accessing the Internet at anytime, either using a built in device, or brought in user devices;
> — equipped with a set of modern applications and dynamic contextual functionalities, offering advanced infotainment features to the driver and passengers;
> — capable of interacting with other smart devices on the road, or in mechanical shops, leveraging vehicle-to-road infrastructure communication technologies;
> — capable of interacting with other vehicles, leveraging vehicle-to-vehicle communication technologies."

This definition is in fact shown in graphical form in figure 3. In this picture the car is in itself a system with a huge number of computing devices and communication buses. Besides it has connections to the Internet (directly or via brought-in devices), with other vehicles, with road infrastructure, with mechanical shops via OBD port. The car typically has a dashboard that is the main device to offer services and applications.

This work has the objective of summarizing the state of the art of the solutions that have been proposed until today, highlighting the customer's focus and the new challenges for car manufacturers, developers and software engineers.

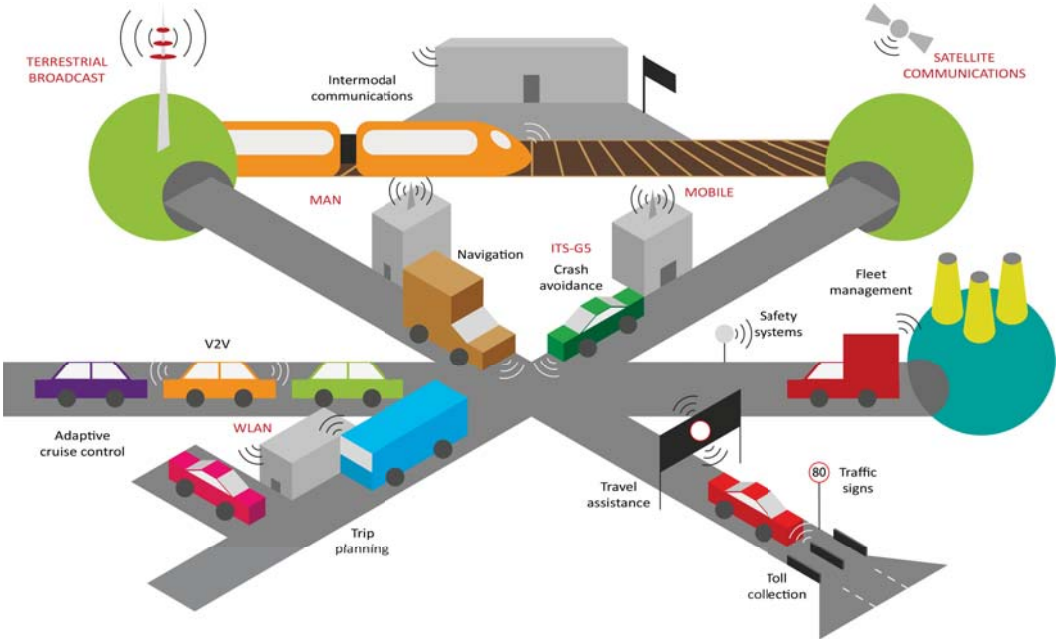


Fig. 4. Different systems interacting in an Intelligent Transport System.

In section 2 we list the main services provided by the Connected Car, typically deployed on the dashboard. In section 3 we focus on the on-board equipment to connect with the Internet, other vehicles, road infrastructure. In section 4 we focus on the dashboard, and notably on development platforms for application and services, and on interaction mechanisms with the end user and brought-in devices (basically smartphones). In section 5 we discuss data collected by cars, considered as moving sensors, uses of such information and legal issues. In section 7 we discuss usability, security and safety in this new Connected Car context.

2. SERVICES

Today, an automobile user may be interested in experiencing all the services and comforts that she would find in a sort of living-room environment, and in doing a great amount of different operations without using her hands. In addition to these functions of information, entertainment (the so-called ”infotainment” services) and interaction, modern cars have to provide in an effective way all the traditional automotive commodities, that may be: real-time navigation and road information, car components management and on-line diagnosis, safety monitoring and alerting.

Intelligent vehicles, and all their services pertaining to security, efficiency, economic and environmental impact, and comfort of the transportation, are part of what is called an Intelligent Transport System (ITS) [Machan and Laugier 2013]. An ITS comprehends not only the vehicles, but also pieces of the road infrastructure (like traffic signs and toll collection machines), pedestrians, and so on. A set of different communication means can be used to make these elements interact with each other. Figure 4 gives a glimpse of the very diverse set of elements interacting.

This section contains a bird’s eye view on the functionalities already provided by current luxury cars, as well as ones that will likely be provided by next-gen vehicles. Although they are not all strictly related to multimedia and Internet, each of them can

take advantage from the use of data coming from the cloud, from advanced applications and graphical interfaces deployed on dashboards, and from the possibilities given by brought-in devices.

For ease of reading, the clustering of services adopted in [Everis 2015], tailored to the driver's point of view, has been adopted also in this paper. Traffic safety services come into play in case of accidents and breakdowns of the car. Infotainment category refers to all services enabling access to multimedia content. Traffic efficiency deals with route navigation and dynamic advice to driver. Cost efficiency comes in handy for decreasing costs bore by car owners. Finally, some utilities not implying the usage of multimedia content are listed in the convenience and interaction cluster.

2.1. Traffic safety

— *Driver's fatigue, anger and stress detection.* Driver drowsiness is among the major causes of car crashes. [Swan 2015] identifies the detection of driver's fatigue -in order to prevent serious or even fatal accidents- as an essential feature of future cars. Several sensors and computer vision applications can be used to spot whether the driver is exhausted or distracted, using eye movement and bio-signal processing [Boon-Giin and Wan-Young 2012], measurements of the time intervals for which the eyes are closed [Ghimire et al. 2015], detection of eye rub and yawning [Manoharan and Chandrakala 2015] and stress patterns in the driver's voice [Siddiqui et al. 2016].

  Driver's stress can be monitored by advanced seats, in terms of heart rate variability [Newswire 2011], or by steering wheel speed sensors [Van Dongen 2014]. Finally, a drunk state can be detected through breath and touch sensors [Usa Today 2015]. Once it is acknowledged that the driver is in a dangerous condition, she has to be effectively alerted (e.g., with a alarm sound emitted by the car speakers).

  Since a great percentage of incidents is caused by road rage, a number of research labs (with valuable work from BMW [Cunningham 2014] and MIT [AutoEmotive 2015]) are trying to add emotion sensing technologies inside the car, in order to dramatically increase the safety of drivers. All those works are based on the assumption that stress is one of the most relevant factors among those negatively affecting driving performance.

— *Accident avoidance and assistance.* The road is analyzed to aid the driver's visual system in spotting risks, maintaining a proper trajectory, and ultimately dodging sudden obstacles. Driving Assistance Systems are composed of several components, performing a set of elementary operations (e.g., Lane Assist or Precrash Systems). [Yenikaya et al. 2013].

  Using radars, lasers and video sensors equipped on car, imminent crashes can be detected and signaled to the driver, or an automatic decision (and subsequent action, in terms of steering and braking) can be taken by the car itself [Mobileye 2015; Pilipovic et al. 2014].

  Lane Keeping and Departure Warning systems are implemented and combined to prevent drivers from deviating from the correct trajectory, with the aid of cameras detecting lane markings ahead, and in the meantime interpreting eye and head dynamics to predict the driver's intention to change direction[Doshi and Trivedi 2009].

  When accidents actually occur, their consequences can be mitigated: Smart SOS systems [P-Dhole et al. 2015] automatically detect occurrence of crashes and notify the nearest service capable of providing road and/or medical assistance. Thanks to the eCall initiative, a system that allows the automatic dispatch of a call to emergency numbers in these cases is already mandatory for new generation vehicles produced in Europe. The final aim of such systems is to minimize the time gap between the crash and the moment when victims receive proper aid. It is estimated that the prompt-

ness in making emergency calls can save up to 2500 lives every year, in Europe alone [European Commission 2013].

— *Night Vision Assistant (NVA) and Head Up Display (HUD).* Advanced augmented reality techniques can be implemented in order to improve driver's visual perception in case of darkness or other conditions deteriorating visibility. Far Infrared (passive) and Near Infrared (active) systems are the technologies currently used for providing Night Vision enhancements [Piniarski et al. 2015].
Visual informations (navigation info, warning signs, major unexpected hazards, highlight on pedestrians crossing the street) can be superimposed on the windshield, in order to maximize the tempestivity of giving the right information to the driver, while minimizing the possibility of distracting her eyes from the road [Haeuslschmid et al. 2015].

— *Remote maintenance, roadside and stolen vehicle assistance.* Information can be gathered on-board, in order to provide them to car manufacturer. This way, in-advance diagnostics of malfunctions are made possible. Unexpected car breakdown occurrences can be fronted by providing the right assistance to the driver. In case of theft, some actions can be taken to block the car or to contact the proper authorities.

2.2. Infotainment

— *Music streaming.* The classic in-car CD player and AM/FM radio is moving towards a customizable, online streaming service like the ones that can be found on every PC or smartphone. Context Aware Recommender Systems (CARS) can be adapted to play particular songs related, in some way, to the environment in which the car moves. [Baltrunas et al. 2011] shows how recommendations for tracks can be adapted to a channel (i.e. a specific kind of music that the user likes), a place or passengers inside the car.
Driving styles, road types, landscapes, sleepiness, traffic conditions, driver's moods, weather and other natural phenomena can be used as different parameters for recommendations. The effects of music volume and tempo on driver's focus can be taken into account to calibrate a more comfortable and safer driving experience (for instance, accompanying the driver out of an anxious or angry mood to a less dangerous relaxed condition).

— *Video streaming, games and Internet browsing.* The dashboard can be equipped with functionalities to make the car multimedia environment as complete as possible. Internet browsing functionalities, as well as video streaming and gaming services, can be provided to users. The activation of those systems must be carefully supervised, since the driver's attention must not be taken off the road: a possible solution is to make them available only for the back seats when the car is turned on.

— *In-car wi-fi networks.* It may be of interest to turn a car into a moving wi-fi hotspot for the use of its passengers, in a more efficient way than just using the tethering function of a smartphone. Wi-fi networks can be recreated with wireless routers installed on car (like MiFi routers produced by Novatel) or with the use of 4G dongles/pebbles [Techradar 2015]. Efforts still have to be made to obtain a functional integration between the network functionalities provided to devices brought inside the car, and the car communication infrastructure itself.

— *Social networks.* Extensive connections between cars, along with vehicle-to-vehicle communication, may enable social interactions among users on the road. People can share with other drivers information about their trip planning, meet similar users thanks to common interests or location proximity, ask for support on the road, or simply share experiences through social networks [Luan et al. 2015].
Existing generic social networks (mainly Facebook and Twitter) can be integrated into car dashboards, or ad-hoc ones (the so-called Vehicular Social Networks or VSNs)

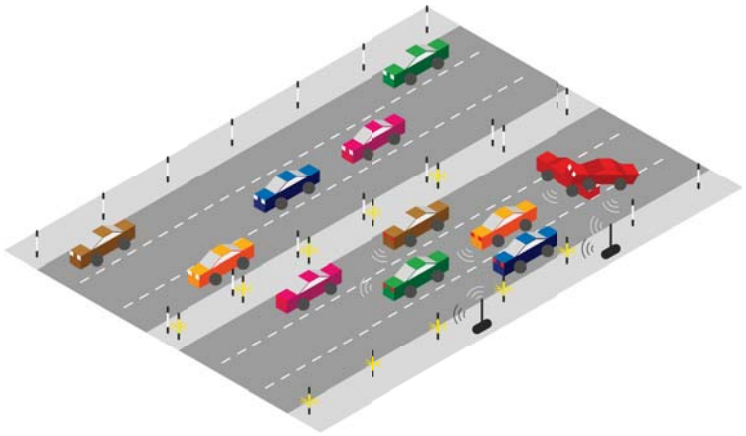


Fig. 5. Cars can be connected to road-side lights to give information about traffic conditions and accidents. (Source: ERCIM News - Online Edition)

can be engineered. Vehicular Social Networks have to cope with nodes joining or leaving at an extremely fast rate, to allow messaging and exchange of multimedia information between mostly anonymous neighbors, and to connect dynamically close users with similar interests, configurations or travel routes [Alam et al. 2015].
Some existing examples are Drive And Share [Lequerica et al. 2010], which bases on the iPhone platform and allows users to share traffic and personal information in real time, and RoadSpeak [Smaldone et al. 2008; Hu et al. 2013], that offers the possibility of entering voice chat rooms with people driving on the same roadway or highway.

2.3. Traffic efficiency

— *Navigation, online route planning, street view.* New generation navigation systems can allow users to plan a route at home and send it to the car, to see photographs and recommendations about nearby places, and to take advantage of real time information to obtain optimal routes. Real time information about fuel prices (i.e. spotting the cheapest gas station in the surroundings) and maps of the available parking spots can be provided as well. Navigation information can be also presented on a contact analog head-up display, thus presenting augmented reality information in the driver's principal sight and therefore avoiding to distract her from driving [Pfannmller et al. 2015].
— *Traffic, weather and road condition monitoring.* Viewing the vehicle as a component in a bigger system, traffic congestion management becomes a fundamental feature for connected cars: vehicle-to-infrastructure communication can be exploited to gather information (anonimously announced by every vehicle on the road) about position, speed, and points of origin and destination of cars, and to send them to other applications in order to prevent road congestions.
Vehicles can work as moving sensors of road and weather conditions, and communicate the information gathered to others, directly or with the intermediation of the infrastructure. The use of information of multiple sensors moving in the same area guarantees the quality of the data provided to other cars. Such services lie under the name of Advanced Traveler Information and Advanced Traffic Management Systems. Autonomous stations on the edge of the road are able to provide information that, combined with the data gathered by on-vehicle sensors, can enable a reliable detection of critical situations on the road. For instance, blocked cars can inform road-side

units about the situation. Figure 5 shows how a connection with road-side units can be used to communicate the presence of a road blockage (which may be caused by construction sites, objects on the road, abverse weather conditions, or car accidents) to approaching vehicles, by means of the activation of warning lights [Jiru 2013].

— *Assisted driving and autonomous vehicles.* Intelligent Driver-Assistance systems (IDAs) are engineered not only to strenghten driver's safety, but also to provide a more comfortable and easy driving experience. With the establishment of automatic brake and speed control, steps have been taken towards a fully Autonomous Vehicle (AV), a technology capable of driving a motor vehicle without the inputs given by a driver [Pilipovic et al. 2014], that will be furtherly investigated in a later section of this paper. With an Autonomous Cruise Control (ACC), the human driver would still be responsible for the vehicle, but the system would relieve him from performing monotonous tasks like holding pedals down while keeping safe distances from other vehicles or lane margins.

  Full vehicle automation results into the notion of Automated Highway Systems (AHSs): the final goal is to remove the human factor as much as possible from the control of vehicles, thus increasing trasportation system capacity, improving safety, reducing environmental impacts of transportation and assuring long term cost savings [McMillin 1998].

  For legal reasons, having fully autonomous vehicles is still impossible in Europe, even though some experiments have been set up in order to prove its feasibility [Pollard et al. 2013].

2.4. Cost efficiency

— *Driver behaviour profiling for insurances.* Insurance telematics allow the usage of dynamic measures (hour and length of each trip, actual total distance traveled, driving conditions for the area, and drivers' ability and behaviour) to calculate the premium. These schemes are known as UBI, or Usage-Based Insurance. Information can be collected by black-boxes, OBD dongles and contemporary smartphones [Handel et al. 2014].

— *Algorithm-based vehicle pricing.* A used car pricing can be evaulated based on a set of dynamic information that accurately describe the car (in a more detailed way than the simple count of kilometers percurred can do). This way, the buyer of the car can make better-informed choices.

— *Energy optimization.* Techniques to reduce and optimize energy consumption can be adopted, calibrating the car functioning and managing the available electrical energy. Interfaces between electric vehicles and smart homes, along with vehicle-to-home (V2H) communication systems can be created, in order to program an effective charging and discarghing schedule for the car, and a set of notifications to the user [Liu et al. 2013].

— *Contextual advertisement.* Advertising industry is starting to offer contextual advertising in cars. Car service industries can advertise their products (for instance, using audio messages) when a potential customer is getting close. The advertising system may receive information about the position of the vehicle and the user's trip, and match them with a particular advertising profile.

— *Vehicle testing.* The vehicle can send back information about its behaviour in difficult weather conditions like ice, dirt, or heavy rain. These information can make the testing done by OEMs easier, and facilitate improvements for future models.

2.5. Convenience, interaction and others

— *Smart Home integration.* Vehicles can be integrated with smart home functionalities, so that drivers can be able to enable devices (such as lighting, heating, entertain-

ment systems or garage doors) before actually approaching home. Two examples of automakers working for integration with smart home environments are Ford (which has provided a connection from the steering wheel to Amazon's Alexa, giving access to devices on its platform like garage doors or lighting systems [Digital Trends 2016]) and Mercedes-Benz (which has joined Nest's developer platform, allowing drivers to give commands to the heating control sytsems of their homes while driving their cars [The Verge 2016a]).

— *Integration with Wearable devices.* New wearable devices can be integrated with the functionalities of a connected car, in order to obtain a smarter and safer mobility. For instance, augmented vision glasses integrated with cars have been presented by Ford, alongside systems monitoring blood sugar levels and heart-rate of the driver through information gathered from smart watches.
For instance, [Boon-Leng et al. 2015] demonstrates how wearable devices can be effectively used for the detection of driver fatigue and drowsiness.
— *Car sharing.* According to estimates, by 2020 car sharing will reach more than 26 millions of users worldwide. Connected car networks can make the dissemination of such services easier, since the movements and the conditions of the individual vehicles can be easily tracked in real-time.
— *Hand-free controls.* OEMs provide specific interfaces that allows hands-free control for various subsystems of the car. Some examples are climate management, music selection, voice calls and message reading if a smartphone is connected.
— *Driver profiles.* Profiles can be set up in order to let drivers configure individual settings in the vehicle, like climate preferences, seat position, favourite radio station. Profiles can also be exported so that they can be used in other cars.

3. TECHNOLOGIES FOR COMMUNICATION

The hardware architecture needed for a new generation car includes a great number of different devices (from the ECUs controlling the behaviour of the vehicle, to the man-machine interface collecting the driver's input), connected one to another via dedicated buses. This section is focused on the part of the architecture pertaining connectivity. We list the various kinds of communications a connected car has to guarantee, and the different technologies that can be used to provide them.

As it is done in [Lu et al. 2014], and also schematized here in figure 3, the information exchanges done by connected car can be clustered under several different kinds of communication.

— *Vehicle To Sensors On Board Communication (V2S)*, or intra-vehicle connectivity, indicates the information transmission between the ECUs and sensors disseminated inside the vehicle. Such an exchange can take place on either wired (e.g., on the CAN bus) or wireless networks. Several alternatives are able to provide wireless connection between sensors and ECUs, like Bluetooth, ZigBee, Ultra-Wideband, RFID or 60 GHZ Millimeter Wave. However, even though wireless communications reduce the amount of cabling needed and provide more versatility to the intra-car network architecture, they are still prone to security and reliability issues.
— *Vehicle To Vehicle Communication (V2V)*, or inter-vehicle connectivity, is the transmission of data between different cars, without the intermediation of a centralized remote hub. This kind of communication is helpful for accident avoidance, route optimization, multimedia information sharing (e.g., pictures about accidents or parking spaces in the surroundings), and social interaction. Communicating vehicles form a vehicular ad hoc network (VANET). Some companies have developed V2P (Vehicle To Pedestrian) technologies to enforce pedestrian security by sending to people alerts about dangerous cars nearby [Quartsoft 2013].

VANETs pose significant challenges for what concerns network management, since the network topology changes constantly and with a very fast pace. Moreover, the dynamic movements of nodes in the network, and the presence of obstacles, may create interruptions and disconnections in the data flow between vehicles. In general, it is assumed that approaching vehicles are likely to stay in a communication range for a limited amount of time, hence the amount of information that can be exchanged is limited [Delot and Ilarri 2013].
Cooperative traffic monitoring, collision warning and message transfer, digital map downloading, value-added advertisement, electronic toll collection and parking availability notifications are some existing examples of application of VANETs [Kumar et al. 2013].

— *Vehicle To Road Infrastructure Communication (V2R)* is the exchange of information between a vehicle and an intelligent road infrastructure, composed of street signs, roadside sensors, traffic lights. It is crucial to enable an efficient traffic management. V2R communications are typically based on Dedicated Short-Range Communications (DSRC).
— *Vehicle To Internet Communication (V2I)* is the fundamental requirement for a connected car: modern vehicles must be able to access to the Internet to experience dedicated services and access to multimedia information. The solutions available today connect vehicles to the Internet using the cellular network infrastructures, using a SIM to allow the vehicle to get connected to the 3G/4G network. These solutions are discussed in a later paragraph.

The whole set of communication means can be called V2X Communication. In the following paragraphs, some insight is given about the IEEE 802.11p Standard (WAVE), and about the technologies allowing the Vehicle To Internet communication. The latter, in fact, is the basic element for the deployment of infotainment and multimedia services on new generation vehicles.

3.1. V2V and V2R - integration and standardization

In 2009 IEEE has moved forward towards a standardization of vehicular connectivity, creating standard ways of accessing services as well as interacting with vehicles produced by different automakers, thus integrating and enforcing V2V and V2R communications. Those efforts have resulted in the IEEE 802.11p WAVE (Wireless Access in Vehicular Environments) standard [IEEE 2009].

The WAVE system consists of Roadside units (RSUs) installed for instance on light poles, semaphores or road signs, and Onboard units (OBUs), carried by moving vehicles. WAVE defines the following elements: the architecture and services necessary to communicate in a mobile vehicular environment; the data storage formats and command messages/responses; secure message formats and procedures and circumstances which need them; network and transport layer services supporting secure WAVE data exchange; necessary improvements to the MAC layer in order to enable the new protocols; formats supporting secure electronic payments in the Intelligent Transportation Systems (ITS) [Uzcategui and Acosta-Marum 2009].

Efforts for the provision of standards and more secure access to vehicle data have been done also by the World Wide Web Consortium, which has recently announced the start of a collaboration with the automotive industry.

3.2. V2I - SIM on car solutions

To provide the driver with a connection to the Internet, or to take advantage of a connection to the 3G/4G network to enable useful services, a GSM SIM card can be carried by a car. A fundamental point is how applications are delivered to the car:

there are three possible solutions pertaining to the SIM on car alternative [GSMA 2013]. The embedded solution prescribes a SIM card permanently installed inside the vehicle, with the applications running on the dashboard. The tethered solution relies on a modem that allows the insertion of a personal SIM; while the intelligence is still a prerogative of the car, the modem can either be part of the hardware of the car or a brought-in device. The integrated solution leaves no intelligence to the car, and relies completely on the user's handset which provides both connectivity and functionalities; the user control panel just mirrors what is running on the external device. In the following list, advantages and disadvantages of the three techniques are discussed.

— With the *embedded* solution, both the connectivity and the intelligence are a prerogative of the car. Embedded SIMs are installed during manufacturing process, and ultimately identify individual vehicles. The technique provides the best communication performance and avoids all possibile tethering issues, thus being really reliable and preferrable when safety-critical services are taken into account. It also has the advantage of relieving the driver of the need to possess a SIM specific for her car, since a dedicated one is permanently integrated inside the vehicle. However, the solution does not leave place for technology evolution or operator change during the lifetime of a vehicle, without expensive hardware intervention.
  Both ETSI (European Telecommunications Standards Institute) and GSMA have provided (respectively in ETSI TS 103 383 Release 12 - 2013/02 and in a publication dated December 2013) a standardized architecture for eUICC (embedded Universal Integrated Circuit Card). However, some proprietary solutions are still deployed on the market by OEMs [Beecham Research 2014].
— The *tethered* alternative keeps the application intelligence inside the car, while decoupling the SIM from the vehicle. The modem used to activate tethering can be embedded inside the car, or brought in with the user's smartphone (or a similar user device).
  An embedded modem is built into the vehicle but a personal SIM must be inserted inside a slot; this allows easier operator change with respect to the embedded solution. The communication is reliable, since it uses the vehicle antenna. However, the solution offers no advantage compared to the fully embedded one, regarding the possibility of technology evolution.
  An external modem takes advantage of the user's phone or a USB modem for the insertion of a personal SIM. This reduces largely the hardware costs for vehicles, and allows the solutions to evolve accordingly to phone evolution. With USB connections, the difficulties of wireless protocols can be avoided. The main problems with this solution are a defective reliability and robustness, and the possible deterioration of user experience.
— Finally, in the *integrated* approach, both intelligence and communication are provided by the phone. In any case, the car has to provide some crucial services: a pertinent user interface to the application, the access to car-related data required by the particular services, and obviously the support for the wireless interaction with the mobile device. In some cases, the human-machine interface (HMI) used to access the services can be located on the mobile, while the car infrastructure is used just to access to car information. At the same time, obviously, mobile devices must be aware of the automotive context, and must adapt to it, providing the user a means to interact with the car [Serafinski and Poland 2013].
  An integrated approach allows the use of up-to-date technology and the finest customization to driver's preferences. It is however difficult to provide a seamless user experience, and several driver distraction issues arise when it is needed to interact



Fig. 6. Two alternatives for providing infotainment applications.

with handheld devices while driving. Moreover, the solution is the less safe and reliable since automakers have no control on which applications are used by customers.

In both tethered and integrated solution, to make the connection between car and brought-in device possible, Bluetooth or Wi-Fi connection can be used. The discussed alternatives are not completely mutually exclusive, since car companies can adopt hybrid approaches. For instance, automakers may prefer to keep the intelligence for safety-critical applications in the car, while leaving that for leisure functionalities on brought-in devices. For instance, in Europe the eCall law dictates that all cars manufactured from 2015 onward mount a SIM card, capable of calling emergency teams in case of an accident.

4. SOFTWARE PLATFORMS FOR INFOTAINMENT

To make connected cars useful and attractive to users, innovative and heterogeneous applications must be developed and installed on the dashboards they provide. The aim of this section is to list all the possible options for a car maker to create and operate applications on its vehicles. The required interfaces and data that the car has to provide are enumerated as well.

A car maker can provide platforms that allow the installation of apps on the dashboard, or otherwise the car can provide just a user interface that appropriately organizes functions and data, relying on applications running on the user's smartphone. Both the alternatives, as well as the solutions used to implement them, are discussed in the following paragraphs. Figure 6 shows the difference between the two techniques. Referring to figure 1, the dashboard contains the communication, navigation & trip computer, and entertainment ECUs, among others.

4.1. Platforms for embedded applications

As it has been anticipated, the first way to grant infotainment services on a car is to allow the use of embedded apps. Traditionally, in-car interfaces have always been created by car manufacturers, leading to proprietary and completely closed systems. New functionalities enabled by connected cars highlighted the need for applications capable of running on systems adopted by more than just one car manufacturer [Feijoo and Gomariz 2015].

These applications can come pre-installed and/or be downloadable on the dashboard, therefore needing not the presence of external devices to work properly. SDKs can be provided to external developers, that will make their applications available on a dedicate marketplace, for car users to download them. Examples of platforms on which such applications are based are listed hereafter.

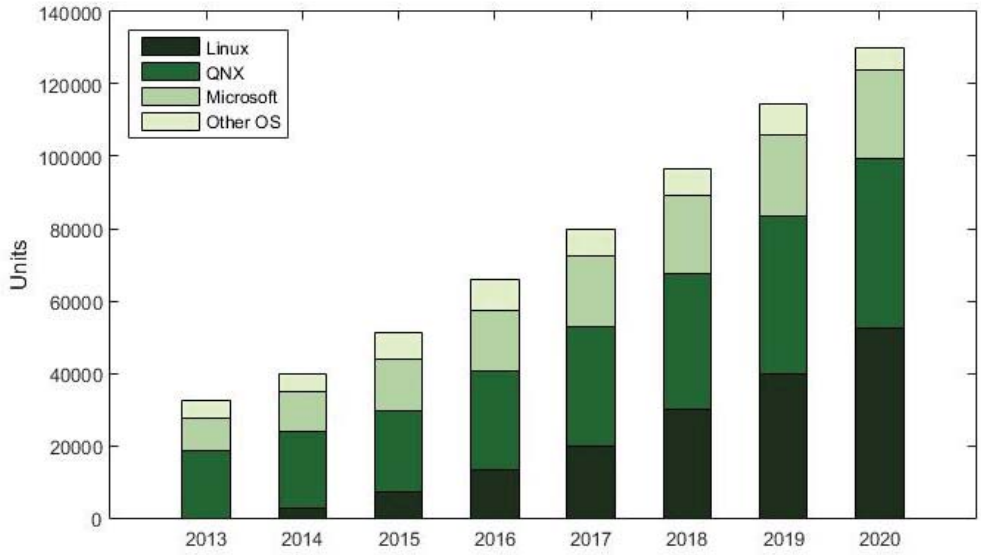


Fig. 7. Automotive Infotainment Operating System sales market share forecasts (Data source: IHS Automotive November 2013).

— *QNX* car platform for infotainment allows the development of customizable apps for radio, weather and location-based systems, and web applications based on HTML5, CCS3 and JavaScript. The system is nowadays integrated by a huge number of HMI systems and connects with smartphones using Bluetooth, DLNA, MirrorLink, USB and Wi-Fi. The platform is based on QNX Neutrino OS, and is optimized to provide fast boot, high-performance graphics and media robustness. The majority of car infotainment systems is currently switching to QNX for automotive.
— The latest version of *Windows Embedded Automotive*, released in 2010, allows the leveraging of Silverlight for the creation of advanced HMI interfaces, the use of TellMe speech technology to enable voice commands, and the integration with a vast set of mobile devices. Windows Embedded Automotive has been the first choice among embedded operating systems for automotive for a long time, since it has been extensively tested and is highly reliable, and it guarantees a high level of innovation, reusability and flexibility.
— *Genivi*[1] [Han et al. 2013] is the name of an industry alliance involving some OEMs working on a open-source infotainment platform for vehicles. GENIVI provides reference implementations and certification programs to those wanting to produce infotainment services. The architecture is based on a Linux Kernel. The alliance's objectives are a shorter development cycle, a faster time to market, and smaller costs for companies for the production of IVI software. GENIVI is based on SmartDeviceLink (SDL), a set of standardized messages and application templates based on the work Ford had done for AppLink.
— *Tizen IVI*[2]. Tizen is an open-source project, part of the Linux Foundation and carried by Intel, providing a free environment based on HTML5 for a set of device categories, such as in-vehicle infotainment.

[1]http://www.genivi.org
[2]http://www.tizen.org

Table I. Comparison between platforms for embedded applications

	Producer	Open Source	Based on	Features
QNX Car Platform	Blackberry	No	QNX Neutrino OS	Multiprocessor support; ISO 26262 ASIL D certification; real-time features; microkernel RTOS; advanced graphic features; power and thermal management features.
Windows Embedded Automotive	Microsot	No	Windows Embedded Compact 7	Support for multi-core IA, ARM v7 and SH4 architectures; phone support with Bluetooth; UI framework extensible via Silverlight; speech engine support.
GENIVI	GENIVI Alliance	Partially	Linux	Focus on open-source distribution and platform standardization; d-bus optimization; audio management; graphical management; automotive diagnostics.
Tizen IVI	Linux Foundation	Yes	Linux	HTML5 and JavaScript development platform; multi-user architecture and login management; multi-seat support; single sign on framework; DLNA; speech framework.
Android	Used by Renault for R-Link	Partially	Linux	Huge app library; advanced GUI; compatibility with the vast majority of smartphones.
Automotive Grade Linux	Linux Foundation	Yes	Linux (Tizen IVI)	Focus on reference distributions or IVI, ITS and other areas; processor-independent; support for multiple hardware architectures; mobile device integration and bluetooth support.

— *Automotive Grade Linux* is an open-source stack for in-vehicle infotainment based on Tizen IVI (of which it is a bootable distribution). It provides a new user interface and support for applications written in HTML5 or JavaScript. According to recent forecasts, the automotive domain is likely to shift from QNX (the current market leader) to Linux in the future: the trend is shown in figure 7.
— *Android* is the basis for the R-LINK system by Renault, a platform open to external developers and equipped with an app market (R-LINK Store). Android has both advantages and disadvantages when it comes to automotive systems [LinuxGizmos 2013]: it comes with a very big app library, and it is the system installed on the majority of smartphones, so the integration with them can be made easier. However, the solution may lack in telematics and safety integration.

The systems listed above allow third-party developers to create applications for cars, in a way similar to what already happens for smartphones. The main problem for a developer approaching the automotive context is the need for a standardized approach for communicating with the car: if it is not available, a specific version of the software has to be created for each car manufacturer. In general, the main car interfaces that must be provided to an application include:

— *Button control* - to inform the mobile about which car buttons have been pressed.
— *Audio control* - to allow audio playback using the car's speakers, and to record voice commands using the car's microphone.
— *Video display* - to enable video streaming from the mobile to the car's dashboard.
— *UI rendering* - to allow the phone to send UI components that have to be rendered in the car's dashboard.

— *Car data access* - to allow the mobile to require car data.
— *Communication control* - to select which communication interface (for instance, Bluetooth) will be used for the communication with the mobile handset.

Table I summarizes the main advantages of the platforms.

4.2. Car-mobile integration solutions

The in-vehicle infotainment functionalities can be provided by an external device: the applications run on a smartphone, and then a middleware is used to allow the communication between the brought-in device and the dashboard permanently installed inside the car.

The dashboard not only displays the application data in a customized user interface (this practice is called screen duplication), but can also allow the user to control it: in the most sophisticated functions available today, the car dashboard can access the phone data and select applications to run by voice commands [Murphy et al. 2014]. Systems must carefully measure the amount of potential distraction procured to the driver by the hand-held device. A possible solution is to make the smartphone screen turn black when it is connected to the car dashboard.

Integrated car-mobile solutions come with huge advantages. First of all, different drivers can automatically customize the services provided by the car carrying their own mobile devices. Moreover, the smartphone can be used as a tethering device instead of creating a Wi-Fi system integrated in the car. Lastly, it is much easier to get applications upgraded if they are installed on a smartphone [Fleming 2015]. The solution is also preferrable for developers, since they can produce applications following the guidelines of a specific smartphone platform, without taking into account the actual dashboard on which they will be mirrored.

The most widespread solutions for car-mobile integration are described in the following list and summarized in table II.

— *MirrorLink*[3] is a solution developed by the Car Connectivity Consortium (CCC). The consortium was founded with the aim of creating global standards for smartphone in-car connectivity, and includes very important car manufacturers like Honda and Mercedes-Benz as well as prominent mobile companies, like Nokia and Samsung. MirrorLink supports the replication of the display of a smartphone in the car, achievable with an USB or Wi-Fi direct connection. MirrorLink creates guidelines for the apps graphics, with large icons allowing an easy and fast navigation among controls on the display. Both the phone and the vehicle must be MirrorLink-enabled in order to make MirrorLink-based applications work. DriveLink, a Samsung application providing a set of phone-car functions, is an example of MirrorLink-based integration system.
— *Applink*[4] is a solution created by Ford, providing something more than the simple display mirroring done with MirrorLink. It is the evolution of the Microsoft SYNC platform previously installed in Ford vehicles. Applink provides an SDK for Android and iOS, capable of communicating with the car and performing various operations within the vehicular environment (e.g., showing messages on the dashboard, playing music with the speakers, offer voice controls and link callbacks to physical buttons). The downsides of the solution are the lack of connection to the in-car navigation system and a poor graphic support.
— *Apple CarPlay* is a solution that enables the connection between an iPhone and car displays, allowing apps to be controlled interacting with the dashboard, voice com-

[3]http://www.mirrorlink.com
[4]http://www.ford.com/technology/sync

Table II. Comparisons between smartphone link solutions

	Producer	Based on	Features
MirrorLink	Car Connectivity Consortium	OS-agnostic	Easy-to-use in-dash control over compatible smartphones (limited compatibility); compatible applications: audiobooks reader, navigator, location sharing system, real time news about road problems, radio and music.
AppLink	Ford	QNX (originally Windows)	Connection to smartphone application through voice commands, internet radio streaming, social media; app-link compatible mobile application available for Android and iPhone (need support by the particular smartphone).
Apple CarPlay	Apple	QNX and other IVI platforms, as a VM	SIRI integration, navigation, smartphone control, music control, iMessage voice control and response, third party application support.
Android Auto	Open Automotive Alliance	QNX and other IVI platforms, as a VM	User interface similar to the corresponding android smartphone one; integration with Google Now, navigation, music control, phone calls, SMS management, web search, car hardware support and monitoring, third party app support.

mands with SIRI and hands-free calls and messages. CarPlay works on QNX, extending the functionalities of the standard infotainment system built in the vehicle with Apple's one, when a iPhone is connected. This approach relieves the car-maker from agreeing to iPhone exclusivity, and Apple from building support for Android, Windows Phone and other phone systems, as it would have been if Apple made the whole stack [iMore 2014]. Some OEMs, like Mercedes and Hyundai, have implemented CarPlay as a simple app, completely separated from controls for climate and navigation system. Competitors like Volvo, conversely, have integrated CarPlay in the principal system of the dashboard, allowing it to access all the functionalities of the car.

— *Android Auto* is the solution proposed by the Open Automotive Alliance (OAA), a joint-venture of both prominent automakers and high tech companies. It is built on BlackBerry QNX. It provides a simple dashboard, allowing the user to access to the navigation system (Google Maps), phone calls, Google music, car analytics and voice commands. Figure 8 shows the forecasts for the market share of Android Auto, compared to the one of Apple CarPlay.

4.3. OBD-II dongles

OBD is the name of a vehicle self-diagnostic and reporting functionality, available since the early 80s. OBD-II is an evolution of such technology, made mandatory for all cars manufactured since 1996. The standard mandates the data and message format, the vehicle's parameters that need to be monitored, the diagnostic connector and the pin scheme. The OBD-II port is tipically placed under the steering wheel, and it is available to technicians to access the vehicle's telemetry, using specific scan tools. OBD-II enables the access to a vast amount of information about the car functioning and the driver's behaviour. [Jaiswal 2014] provides a list of examples of data that can be collected.

OBD-II dongles are adapters that allow the user to access the data extractable from the diagnostic port (see figure 9). A smartphone or a computer can be connected to a dongle (via USB or a 3G/4G connection), so that applications running on them can take

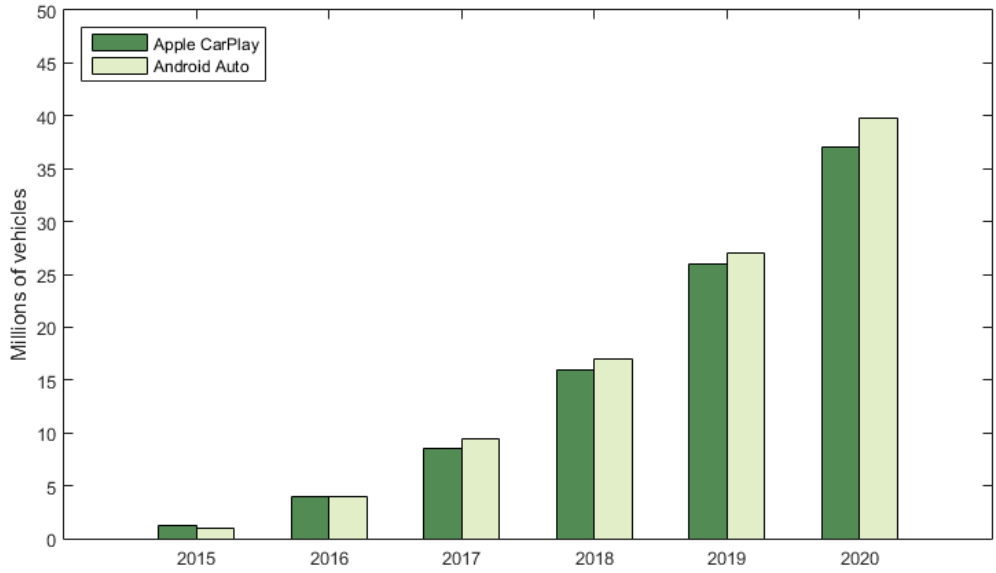


Fig. 8. Sales of cars running Android Auto vs Apple Car Play - forecasts. (Source: BI Intelligence)

advantage of information about the vehicle functioning. OBD-II dongles can enable a very diverse set of applications. The advantage of such devices is the possiblity of enabling the use of new generation automotive applications, as well as the integration with mobile devices, on car produced even twenty years ago.

A vast array of alternatives are available on the market, providing a very diverse array of functionalities: *Carvoyant*[5] is able to alert the driver about disfunctions of the vehicle or bad driving habits, and provides APIs for the development of applications leveraging such data; *Dash*[6] provides the access to information about the car (e.g., location, speed, RPM, current fuel level) and provides as well a set of APIs to developers; *Automatic*[7] enables interaction with wearables devices (e.g., Apple Watch and Pebble Classic), gives suggestions to the driver to let her drive more efficiently and safely, and allows an automatic connection to well-reviewed mechanics to fix occurring problems; other dongles, like *Mojio*[8], *Vinli*[9], *Zubie*[10] and *Mobley*[11] offer wireless hotspot functionalities to the occupants of the car, while providing compatible applications for location monitoring, money saving, route calculation and so on.

However, this way of using OBD-II ports is seen by many as a major security risk for the vehicle industry. As Chris Valasek, security lead at Uber Advanced Technologies Center, points out, “anything that is connecting to the car the Internet provides additional attack surface, especially when it is plugged in the diagnostic port” [Tom’s Guide

[5]http://www.carvoyant.com
[6]http://dash.by
[7]http://www.automatic.com/home
[8]http://www.moj.io
[9]http://www.vin.li
[10]http://www.zubie.com
[11]http://www.att.com/devices/zte/mobley.html



Fig. 9. A dongle can be connected to the OBD-II port to allow brought-in devices to access vehicle data.

2015]. Some experiments have proved that is possible to install malicious software via OBD-II port.

Moreover, it is worth to point out that most of the functionalities offered by OBD-II adapters -in addition to the access to telemetry information- are already integrated into the latest generation of connected cars. For this reason the use of the OBD-II technology for navigational, utility and infotainment purposes must be seen as an interim solution to be deployed on older vehicles, thus destined to be abandoned in the future.

5. FLOATING CAR DATA

It is evident, considering the services listed in the previous sections, that data collection is crucial to extend the horizon of connected car services. Cars on the road collectively work like distributed networks of sensors, constantly gathering various kinds of data. Such information can be called Floating Car Data (FCD) [Messelodi et al. 2009]. In its most elementary shape, Floating Car Data can simply consist of the geolocation data tracked by the driver's smartphone. However, it can also be enriched with internal data about the driver and the vehicle itself, or be combined with information gathered from the surroundings of the car, or from the Internet. Traffic management is one of the applications that can take the best advantage from this kind of information (see section 2.3).

To collect internal data, vehicles have been equipped for decades with a vast array of sensors: multi-purpose cameras to monitor the drivers face or lane markings outside, Stereo Vision cameras to spot hazards on the road, Infrared cameras to provide night vision assistance, radars and LIDARS (LIght Detection And Ranging Systems) to generate mappings of the surroundings, GPSs to provide geo-location information, wheel encoders to measure the actual speed of the car, biometric sensors to observe the condition or habits of the driver [Pilipovic et al. 2014]. With the deployment of V2V and V2R techniques, data collected by different vehicles can be transmitted between them, compared and integrated, in order to gain a better knowledge of the real situation on the road.

Since data can be also leveraged by new-generation infotainment applications installed on cars or smartphones, it may be useful to enrich it using information already available on other platforms. As it is pointed out in [Murphy et al. 2013], there are many external data sources from which applications can extract information to be integrated with the one pertaining vehicles and their drivers. Google datasets, for instance, maintain a very big amount of data that can be very attractive for an in-vehicle usage. Interesting opportunities are offered by Google Maps API, that enables having data about routes and maps constantly downloaded from the web, possibly with the mediation of a hand-held device. Google Calendar API can be integrated with automotive applications to keep track of the driver's meetings and optimize the navigation functionalities. The Google+ API offers access to social data, explotaible by in-car applications. Facebook datasets are important sources of information as well: social data

(e.g., reviews for places in the surroundings or positions that have been visited recently by friends) can be collected and used to enhance the driver's routes. Information about upcoming events nearby can be obtained as well. In general, every service that has an important location component (e.g., search and discovery services like Foursquare[12], or travel review platforms like Tripadvisor[13]) can serve as a valuable source of data for automotive applications.

It is clear, at this point, that data handled and exchanged by cars is practically data about everything. This very manifold information becomes an important asset for car manufacturers, since it can be used to tailor the services offered to their customers in the best possible way. Every party involved with a car's lifecycle, including insurance companies, leasing companies, emergency responders and other stakeholders, can take advantage of such data.

5.1. The privacy issue in the Cloud

The amount of data gathered by cars is obviously massive, and must be sent to the cloud to be disposable for other drivers, carmakers and companies. According to some forecasts [Quartz 2015], on a time window of just an hour, more than 20 GB of information will be uploaded by a single vehicle. To make the management of such a quantity of data feasible, it is fundamental that the cloud does not simply act as a data storage; it has to provide processing and analytical capabilities, and to act as a central hub where all information will pass through.

Car manufacturers and service providers must address all the problems coming from the management of such a big amount of sensible data. First of all, it is important to discriminate the valuable information from the useless one, carefully managing data costs. Big data anaylsis techniques have to be used to manage information, and external datasets must be accessed and combined to generate supplementary insights. Proposed solutions have to cope with the needed processing velocity of extracted data, and to interface with the variety of the data they must interact with (i.e. many sources, possibly having different formats to represent the same kind of information).

The major issue about on-board data collection is managing the protection and privacy of such data. In 2014, in the United States, a group of prominent automakers has agreed voluntarily to a set of privacy and data security principles [Privacy Matters 2015], listed below:

— *Transparency*: companies must tell their customer what information they are collecting, and how and when they will use it.
— *Choice*: companies need the consumer's consent before sharing sensible information or using it for marketing purposes.
— *Respect for context*: data can be exploited or transmitted only in modalities strictly related to the particular context where their acquisition takes place.
— *Security*: technologies that -if used properly- bring major advantage to their users, can also allow governments, advertising enterprises and even criminals to track people's movements. Critical data, especially if the services are able to actually control the car, must be protected from hackers.
— *Data Minimization, De-Identification & Retention*: personal information about customers must be gathered exclusively to perform legal operations, and whereupon, if no longer needed, they must be discarded.

A significant percentage of the sample (about the 37%) of a recent study carried out by McKinsey is opposed to the idea of driving a connected car, since they are frightened

[12]http://www.foursquare.com
[13]http://www.tripadvisor.com

by the possibility of sensible information leaks. A bigger number of respondents, about the 54% of the sample, is afraid that malicious people can manipulate the car from the outside, if it is connected to the Internet [McKinsey Insights 2014].

6. AUTONOMOUS CARS

One of the most discussed topic in the automotive market, these days, is the possibility of a massive deployment of autonomous (fully or partially) vehicles in the coming years. The development of sensing technologies, as well as vehicular communication technologies -as seen in previous sections- have paved the way for advanced functionalities allowing cars to sense their surroundings, to plan and communicate their decisions, and to finally actuate them without any human intervention.

The concept of a car driving without input from a human has been an engineering fantasy for almost a century: according to [Bimbraw 2015], it is possible to pinpoint the first antecedent of autonomous vehicles in the Linriccan Wonder radio controlled car, demonstrated in New York City in 1926. Several other important steps have been made through the Twentieth century. What follows are just some examples: the Firebird cars engineered in 1959 by General Motors, able to autonomously drive on highways; an autonomous van, able to drive on empty streets leveraging vision capabilities, released by Mercedes in 1980; the 1995 NHOA (No Hands Across America) project, in which a semi-autonomous car managed to drive for 5000 kilometers with the aid of human intervention for just 1.8% of the time.

A big boost to the development and to an intensive road test of autonomous car technologies was given by three challenges patronized by DARPA, a research section of the United States Department of Defense. While the objective of the first two Grand Challenges was to move robots autonomously -with the aid of sensors- through desert terrain for 132 miles [Thrun et al. 2006], the 2007 Urban Challenge was focused on driving in urban scenarios, and the participating vehicles had to comply to Californian traffic laws while performing three ”missions” of about 30 kilometers each.

Outstanding results were also obtained in 2010 by the VisLab Intercontinental Autonomous Challenge (VIAC), in which vehicles equipped with low-cost vision technology travelled in almost complete autonomy for a 13000 kilometers-long trip from Parma, Italy to Shangai, China [Broggi et al. 2013].

Latest years have seen numerous prominent automakers and technology leaders approach the niche of autonomous driving. Google Self-Driving Cars have hit the road in big numbers (licenses have been given for 73 cars [PC World 2015]), and the technology that’s moving them will be deployed on FCA-Chrysler vans [Autoblog 2016]. While semi-autonomous ADAS (Advanced Driving Assistance Systems) are already (or will be soon) available in luxury cars, numerous OEMs have revealed the concepts of their own fully automated prototypes; some of them are exploring new possibilities (e.g., some companies have jointly tested platoons of *robot trucks* [BBC 2014]) or have tested autonomous vehicles in new environments (e.g., Ford has run tests on the snow or in the darkness [PC World 2016]). Testing reports, open platforms and algorithms have been published as well in scientific literature [Kato et al. 2015].

The aim of this section is to present some details about the current state of the art of autonomous driving, listing the possible classifications of autonomous cars and highlighting their fundamental functionalities, advantages, drawbacks, and possible opportunities.

6.1. Definition and main functions

A possible definition of an autonomous car is given by Jo et al., as *“a self-driving vehicle that has the capability to perceive the surrounding environment and navigate itself without human intervention”* [Jo et al. 2014]. However, frequent definitions in liter-

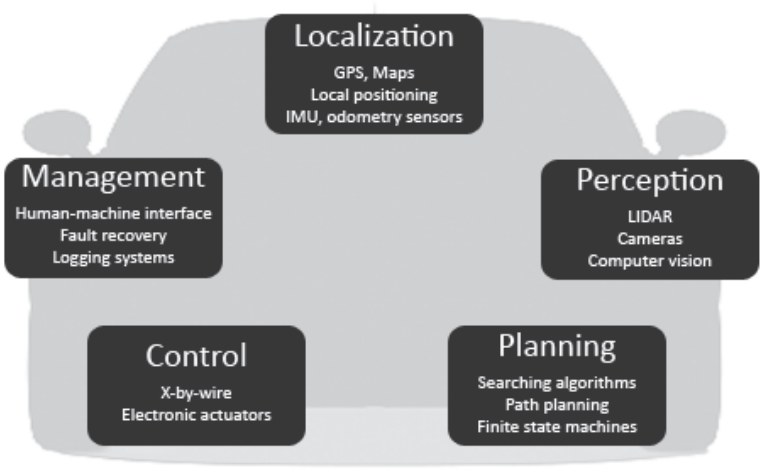


Fig. 10. Functionalities of an autonomous vehicle.

ature consider a car as autonomous even if it is not completely independent of the presence of a human being on the driver's seat. A classification of cars according to the level autonomy they provide has been given by SAE (the Society of Automotive Engineers) [SAE], which defines six possible levels of autonomy as follows:

— *Level 0 or No Automation* - the human driver has to control every driving functionality.
— *Level 1 or Driver Assistance* - at this level, the automation is function-specific. The car can automatically steer or accelerate, but the overall guiding task is still performed by a human driver. Some examples of driving assistance systems are the Lane Keeping Systems, discussed in Section 2.
— *Level 2 or Partial Automation* - more control functions are integrated, and the vehicle can actually drive autonomously. However, the presence of the driver is still essential, in order to monitor the car functioning and the surroundings. The driver has to identify possible dangerous situation, and to take the control back to get over them.
— *Level 3 or Conditional Automation* - the car monitors its functioning and the surroundings, and informs the driver -with a takeover request- when she has to regain control. [Bahram et al. 2015] lists some situations in which a takeover request may have place: when a planned autonomous route ends (e.g., the car is exiting a highway stretch) and manual control becomes mandatory; when the surroundings change suddenly and in an unexpected way (e.g., the sensors recognize an unknown object); when software or hardware failures happen. Takeover Requests shall be sent with a minimum advance with respect to the moment when manual control is needed, in order to prevent the driver from being caught unprepared and eventually panicking.
— *Level 4 or High Automation* - the car can manage by itself emergency and unexpected situations, if the human user is unable to respond positively to a takeover request.
— *Level 5 or Full Automation* - the driver's presence inside the car is no longer needed at all. All the driving decisions normally managed by a human driver, through various environments, can be performed by the vehicle.

Most automakers, by now, are providing Level 1 functionalities on their vehicles, although some OEMs like Volvo have mounted Level 2 capabilities on their luxury

models [Fortune 2015]. The ongoing research carried out by Google is aiming at a release of a Level 3 autonomous vehicle in 2018 [Fehr And Peers 2015].

Whatever the level of automation reached, in general an autonomous car must provide a set of five fundamental functionalities. They are synthesized in fig. 10, and described in more detail -with a glimpse on the technologies used to obtain them- in the following:

— *Localization* - global localization systems are used to obtain at any moment the absolute coordinates of the vehicle. In addition to them, local positioning systems, capable of creating mappings of the immediate surroundings, are used to obtain a finer estimation of the road that is being percurred [Wei et al. 2013]. For instance, the vehicle described in [Jo et al. 2015], which competed in the 2012 Autonomous Vehicle Competition, improves the raw data given by a GPS with the use of additional motion and visual odometry sensors, and with digital maps.
— *Perception* - autonomous cars must be able to analyze the environment around them, in order to maintain a safe trajectory without colliding with objects on the road or other vehicles. The use of multiple sensors is encouraged, to cope with the very diverse set of elements that have to be detected (e.g., pedestrians, bicycles, road signs): the information gathered through different kinds of sensors is therefore merged through data fusion techniques, in order to leverage their advantages, and mitigate their limitations [Grisleri et al. 2008].
  Computer vision algorithms are used to identify details about the detected objects, and to estimate how much an impact with them would be dangerous if not avoided.
— *Planning* - inside the context of a planned high level route that has to be performed, the vehicle computes atomic path variables like speed, brake and steering. This is done based on the information gathered during the localization and perception steps, and complying to traffic rules.
  This functionality leverages searching algorithms (to compute optimal routes from the start to the end of the path), finite state machines (to choose driving behaviours according to the actual driving state and in compliance to traffic law) and path planning algorithms (to eventually decide the actual operations to perform).
— *Control* - X-By-Wire systems and fully electronic actuators allow the automatic execution of low-level driving operations. For instance, the autonomous vehicle proposed in [Broggi et al. 2013] uses three electronic actuators for steering, accelerating and braking.
— *Management* - the vehicle must gather statistics about its functioning, and it must be able to eventually enter fail management modes. A comprehensive human-machine interface should be provided to the driver, that must be able in any moment to regain control of the vehicle, shifting from autonomous to manual mode and back.

The driver assistance solutions installed until now in marketed vehicles have always been realized with the simple aid of arrays of sensors mounted on the car body. As pointed out in [KPMG], such an approach, albeit being already extensively tested, exposes a series of limitations: first of all, mounting a full equipment of sensors on a car is expensive; secondly and more importantly, the exclusive use of sensors limits the discovery of the situation on the road to the immediate vicinity.

V2X communication technologies (discussed in more detail in section 3) give new possibilities to autonomous cars, since they create the opportunity for a constant cooperation between different vehicles and between vehicles and intelligent road infrastructure, thus making tasks like route planning and accident avoidance much easier. Anyway, since connected solutions are based solely on interaction between different nodes, they are useless before they reach a substantial market penetration and without large invetments in road infratsructure.

A convergence between the two different paradigms would therefore be useful for the diffusion of autonomous cars, since it may provide a finer localization and perception than techniques based on sensors only, and reduce the equipment cost for vehicles, after the necessary investments on network and road infrastructure are performed. Functionality redundancy -a fundamental quality of safety-critical systems- would be provided as well.

Finally, [Jo et al. 2014] shows the advantages of a shift to a decentralized architecture for the hardware and software of autonomous cars. Current cars present a centralized system architecture, in which all the actuators and sensors are connected to a central computing unit. Albeit being simpler and cheaper, such an architecture exposes some scalability and reliability issues when the fusion of data coming from numerous sensors is needed. Thus the adoption of distributed architectures may be advisable, since it can ensure superior reliability, extendability and maintainability.

6.2. Possibilities and barriers

The adoption of autonomous and possibly unmanned vehicles comes with a number of indisputable advantages, going beyond the simple enthusiasm for cars driving themselves. The new technologies would result in significant benefits for road safety and traffic management, for the finances of institutions, but also for time management and productivity of the individual users. In the following we list some of the most substantial:

— *Safety* - as is reported in a recent fact sheet by the World Health Organization [WHO 2015], the number of people killed by accidents involving cars every year amounts to about 1.25 million, half of which consisting of pedestrians and cyclists. This number is expected to grow in future years, in the absence of corrective measures.
In general, 90% of car accidents are caused by human mistakes [NHTSA 2008]. In addition to that, NHTSA[14] and CDC [CDC 2015] report that, in 2014, about the 30% of casualties on the road were caused by alcohol-conditioned driving (and 16% by drivers under the effect of other drugs). It is clear that those situations may be nearly completely avoided with the diffusion of autonomous vehicles: [Bimbraw 2015] forecasts that new technologies may prevent 5 million deaths between now and 2020. A total crash elimination would also result in different, lightweight designs for the car cabins, since today's cars security measures and very robust bodies would be no longer needed. Smaller investments would also need to be placed in the deployment of road signage and traffic police.
— *Traffic optimization* - the technologies under discussion would sensibly enhance the traffic situation, by reducing congestions and optimizing the traffic flow through a continuous communication between vehicles. This advantage is of course related to the previous one -given that it is estimated that 25% of traffic jams are caused by incidents [FHWA 2005]- but the traffic situation on the roads can also benefit of other reasons, such as the enlargement of safety distance, or the reduced time spent by drivers searching for parking spots (since the car itself could implement automatic and optimized search mechanisms).
— *Improved energy efficiency* - the reduction of congestions and delays would also result in a significant reduction of emissions and energy consumption. Self-driving vehicles would also consume fuel in a more efficient way than human driven vehicles.
— *New vehicle ownership paradigms and business models* - today, personal cars stay parked and unused for most of the time. Autonomous vehicles would make car sharing easier and more effective, with fleets of driverless vehicles capable of picking

[14] http://www-fars.nhtsa.dot.gov/Main/index.aspx

travellers, leaving them where they need to go and then serve other persons (the so-called *self-driving taxies* forecasted in [Sightline 2013]).
Young, elderly and impaired people, or people currently unable to drive for any reason, would be given the possibility of being on the road. Moreover, with no need of accompanying those people, the amount of cars on the road would be reduced.
New insurance models would be needed for cars that are uncapable of crashing and breaking the traffic rules [KPMG 2015].

What is clear from the benefits listed above is that, once widely deployed and operational, autonomous cars can create substantial economic savings not only for individual customers, but also for organizations and nations. [Fagnant and Kockelman 2015] gives some estimates about how much the United States would save thanks to the diffusion of autonomous vehicles: savings would amount to around $17 billion per year with just a 10% of penetration of autonomous cars in the market, and around $355 billion with a 90% penetration. [Morgan Stanley 2015] estimates $5.6 trillion savings per year worldwide.

Despite these clear advantages, anyway, several studies have pointed out that autonomous vehicles come with a number of issues making a concrete adoption of such technologies difficult and even questionable, at least in the short term. We summarize some of them in the following:

— *Costs* - as reported by [The Wall Street Journal 2013], just the installation of LIDAR systems actually costs from $30,000 to $85,000, resulting in a price for the whole car that is obviously unaffordable for the average automobile user. Without drastic drops, price will be a serious obstacle for the penetration of the technology in the market.
— *Technology and Standards* - there is still need for solid research for all autonomous vehicle techologies to be deployed on mass-marketed cars and not just on prototypes. For instance, V2V communication technologies, which are fundamental for overcoming the remaining issues of sensor-based autonomous cars, are still far from being extensively deployed.
Standards should be developed to regulate verification and validation, to ensure reliability, and to protect the privacy of the data collected and exchanged (this issue has been discussed in section 5).
— *Coexistence with non-autonomous vehicles* - in February, 2016 a Google Car caused the first reported car crash caused by a self-driving vehicle [The Verge 2016b]. The accident was caused by a car making contact with a passenger bus after having predicted -wrongly- that it was stopping. As acknowledged by Google itself in his montly report, *"this is a classic example of the negotiation that's a normal part of driving - we're all trying to predict each other's movements"* [McKinsey Insights 2016]. Until vehicles driven by humans will still be on the streets, there will always be risks associated to missing negotiation (often made, by motorists, with simple glances) and incorrect predictions.
— *Skepticism* - customers may not want to replace their traditional cars with self-driving vehicles: they may find them dangerous or useless, or may not want to give up the activity of driving, which is found as pleasing or funny by most drivers. OEMs should therefore try to build interest and trust about their products, and to involve the demographics that might be more intrigued by revolutionary technologies.
— *Unemployment* - not only drivers would lose their jobs, but also truckers, insurers, traffic wardens and all the professionals working in sectors related to traditional driving.
— *Liability* - lawmakers should define clear rules about who is accountable in case of accidents involving autonomous vehicles. Several automakers -Google, Mercedes and

Volvo to name some- have assured that they will accept complete liability in such cases [IEEE Spectrum 2015].

Overcoming these difficulties, despite some optimistic predictions from research and market leaders (like Tesla, stating that driverless vehicles can become a reality within two or three years [Recode 2015]) will likely require intensive research and test, at least until early next decade.

7. CHALLENGES FOR SOFTWARE ENGINEERING

Traditional in-vehicle software (the one installed on ECUs) has always had different requirements with respect to other software domains, in terms of reliability (the failure rate has to be about one part per million in a year), security, functional safety, real-time behaviour, resource consumption and robustness [Mossinger and Bosch 2010]. Moreover, ECUs are partitioned into different categories (e.g., powertrain, chassis, infotainment) each one emphasizing some specific needs. Therefore, a whole set of challenges has come for the discipline of software engineering, which also had to take into account the peculiar aspects of the automotive domain.

Some of the particular characteristics of the automotive software that may present challenges for software engineering are: the particular distribution that labour has always had in the production of an automobile; the very heterogeneous nature of software, and the consequences it has for what concerns the ease of system integration; the average lifecycle of a car, that may reach 15 years and as a result make software upgrades extremely problematic; the large amount of variants and configurations existing for each piece of automotive software and hardware; the huge number of processors that have to communicate to make even the most basic services possible; the unit-based cost model that is used in the car industry and its consequences; the need for a requirements engineering phase equally distributed among the OEM itself and the suppliers that will actually implement the functions [Broy et al. 2007; Pretschner et al. 2007]. Just to mention one of the measures taken to cope with those problems, efforts have been made to standardize software instead of making it ECU-specific: the AutoSar (Automotive Open System Architecture) partnership, established in 2003, has provided common global standards for ECU architectures, basic software, standardized inter-ECU and intra-ECU communications, and common interfaces for application software.

Once the new generation vehicles opened the automotive domain for the development of consumer application as it is done for devices like computers and smartphones, a whole set of challenges generated for the software engineering world, pertaining to non-functional aspects of software like usability, safety or security. Some of them are summarized in the following.

7.1. Security

Even though in-vehicle wireless connections and diagnostic information extraction do pave the ground for new useful services, they may be exploited by malicious actors to threaten the security of car occupants.

Since connected cars already enable functonalities like keyless entry, preconditioning or window opening, hacking them can lead not only to the less of private data, but also to vehicles getting stolen. Even more catastrophic scenarios could see a hacker to remotely take control of the steering and brake functions of a vehicle, thereby creating serious risks for the life of people.

As it is pointed out in [Becsi et al. 2015], security issues for connected cars can come from different elements of the car, listed below. Some of the possible attacks are shown in figure 11.

— *ECUs*. Thanks to fragile authentication systems -or no authentication at all- ECUs can be reprogrammed with malicious software.
— *Mobile apps*. Applications running on mobile devices integrated with the in-car dashboard can be not adequately protected. Apps may contain malicious libraries exposing vehicle data. Even more serious threats may arise when those apps are allowed to issue commands to the car.
— *Embedded apps*. The vulnerabilities of open source applications, installed on the in-car dashboard, can be exploited to inject malicious software.
— *OBD-II port*. The mandatory OBD-II port gives access to the full range of the automobile bus system. A compromised third-party device plugged to it can collect diagnostic data or also install malware inside the vehicle. If an attacker leaves a dongle plugged to the car, he can constantly sniff sensible information about the vehicle and its users [Carsten et al. 2015].
— *CD-players and USB ports*. Vehicles provide CD players an external digital multimedia port, that can be used for the insertion of malicious software. Since entertainment systems are connected to the CAN bus, they may serve as an interface to attack other components [Checkoway et al. 2011].
— *CAN*. The internal networks of the car are a considerable source of weakness, since they are not equipped with protocols that guarantee key properties of information security, like authenticity or confidentiality of the transmitted data. The CAN bus is used to communicate to all the drive-critical components of the vehicle, and the messages on it are readable by other nodes since they are not protected by MACs or digital signatures [Ring 2015; Kleberger et al. 2011].
— *Wireless Networks*. It is possible, even if not trivial, to hack Wi-Fi and Bluetooth networks, used to connect mobile phones and in-car devices. GSM connectivity has a similar type of vulnerability, and thus serious risks can arise when the car has an integrated SIM card and is directly connected to the 3G/4G network.

Some studies and on-field experiments have demostrated the feasibility of attacks involving ECUs and CAN buses starting from a malicious smartphone application [Woo et al. 2015], and proposed solutions based on encryption, authentication and an efficient key management, or the adoption of hardware security models [Schweppe et al. 2011].

The Alliance of Automobile Manufacturers has launched Auto-ISAC (Information Sharing and Analysis Centre) in July 2015 to address the problem of cyber-security for connected cars [Auto Alliance 2015].

7.2. Usability and Safety

Until a few years ago, the primary concern was to guarantee passive safety to the car occupants, ensuring high reliability of both hardware and software components in a way similar to what has been granted for a long time by avionics software. The ISO 26262 standard for automotive software has been released in November 2011, with the aim of adapting the IEC 61508 standard for programmable electronic safety-related systems to the particular needs of electrical and electronic systems mounted on passenger cars. The key components for the compliance to ISO 26262 are Automotive Safety Integrity Levels (ASILs). They provide a classification of safety risks related to an automotive system, in terms of the consequence of the occurrence of a failure on the driver and road users, the controllability of the hazard and the exposure to it (e.g., ASIL D represents the highest possible risk, that is the presence of fatalities in the community). For instance, if a lag of the rear-view camera display can cause at most moderate damages and injuries, and therefore is labeled with ASIL A, an unjustified



Fig. 11. Some examples of issues for connected car security. (Vector Graphic Source: http://www.WebDesignHot.com)

airbag deployment is tagged with ASIL D, since it can cause life-threatening injuries to car occupants.

With the diffusion of In-Vehicle Infotainment systems, and the integration of smartphones with car dashboards, the attention has partially switched from the compliance to safety standards to a careful design of user interfaces. The interaction with the interface has to be efficient and not time consuming, in order to minimize the number of visual-manual distractions for the user, thus ensuring a safe driving experience to her and to other drivers in the surroundings. Therefore, engineering effort must be spent in the design and development of non-visual interaction models.

As it has been pointed out in [Heikkinen et al. 2013], different regulamentations have been enacted to quantify and limit the distraction caused to drivers by IVI systems. According to [Geiser 1985], there are three kinds of operations among whose the driving experience can be categorized: operations relevant to car maneuvering are classified as primary tasks; operations pertaining driver's safety (for instance, the activation of turning signals) belong to the class of secondary tasks; all the functions not contained in the first two categories are considered tertiary tasks. Obviously, adopting this classification, infotainment applications fall into the last cluster. Sets of guidelines [Stevens et al. 2002] and measures of usability and safety of IVIs are available in literature, and give a practical and measurable advice (e.g., volumes of alert messages, sizes of buttons and fonts, etc.) for the realization of applications regarding tertiary tasks. For instance, NHTSA (National Highway Traffic Safety Administration) has released sets of design guidelines to minimize the distraction caused by in-car components [NHTSA 2010]. Studies quantificating the amount of distraction provided by infotainment devices, like touchscreen display or brought-in smartphones, are available as well [NHTSA 2013].

To aid the search for functional yet not-distracting interfaces with devices, [Rydstrom et al. 2009] studies how much drivers rely on visual clues or haptic information, and how much the driving performance is degraded by these two kinds of messages. [Kern and Schmidt 2009] gives a categorization of input and output modalities provided by a common car, thus allowing the possibility to evaluate the ergonomy and the advantages of every possible UI. Studies like [Consiglio et al. 2003] have focused their attention on the importance, for the amount of distraction provided to the driver, of the cognitive load of the information she receives.

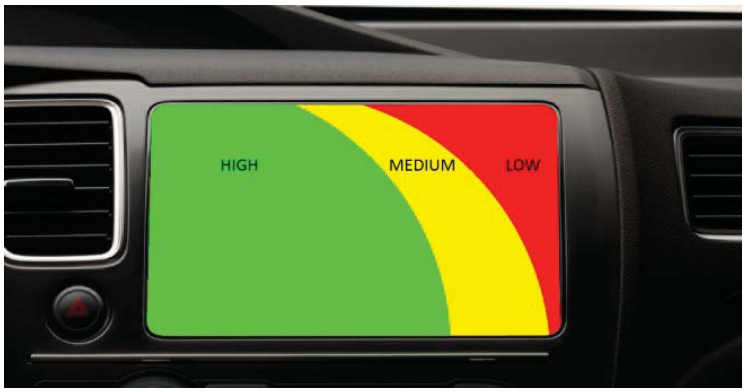


Fig. 12. Reachability for different areas of the in-car dashboard.

As it is explained by the insights and examples provided by [Young and Zhang 2015], excessive complexity has to be avoided when the interface for an in-vehicle application is designed. The platform appropriateness concept must also be taken into account: it encourages the placing of the buttons in places of the user interface that are easy to reach for a user who's sit in the driver's seat (figure 12 shows the levels of reachability for different areas of the dashboard GUI, for a common left-hand drive car).

For instance, Google provides developer with a set of strict guidelines[15] about GUIs of Android Auto applications. All applications use a standardized UI with a few big buttons placed at the bottom of the screen and contextual "cards" at the center, and change their color theme to follow day and night transitions (figures 13 and 14).

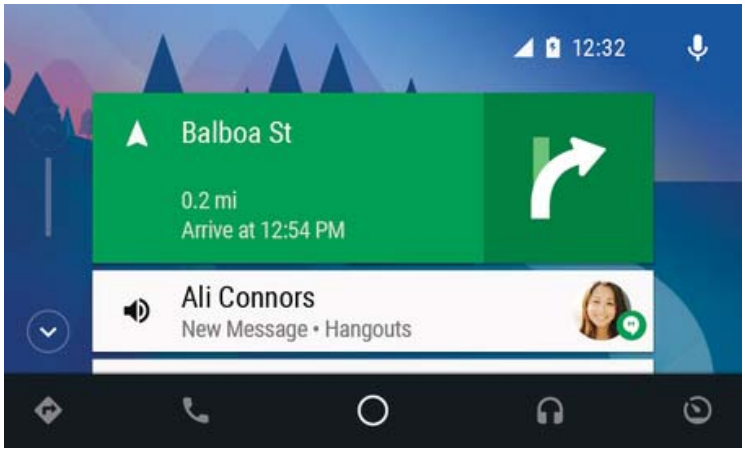


Fig. 13. An example of overview screen for Android Auto. (Source: http://developer.android.com)

However, applications must also be engineered in order to meet in the best possible way the user's expectations, ensuring a sufficient level of usability and efficiency. For instance, the connection to external devices brought inside the car and the information sharing between them should be done automatically, without human intervention. Users should be able to share and access information seamlessly using various devices.

[15]http://developer.android.com/design/auto/index.html

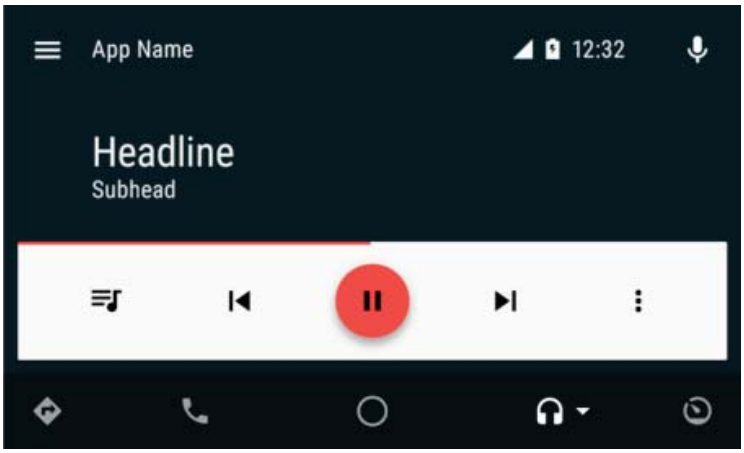


Fig. 14. A generic UI for an Android Auto audio app. (Source: http://developer.android.com)

IVI systems must be context-aware: contextual information can be used to take automatic decisions without user's intervention, to notify sudden changes in the driving context, or to adopt a different presentation style for infotainment services. Finally, since the car has become a social environment in which various subjects interact, IVI systems must be designed to interact with multiple users, while obviously protecting the privacy of them all.

8. FUTURE SCENARIOS

As it has been introduced in the previous chapters, cars connected to the Internet pose an amount of serious challenges and attractive perspectives when it comes to hardware design and software development.

Many automakers have announced plans to sell driverless cars by the end of the current decade or the start of the next. Reliable communication, vehicle management and navigation systems are essential points for such a goal to be obtained. Major hardware companies have also engineered systems for autonomous car. For instance, Nvidia has developed hardware for autonomous vehicles, specifically designed to enable deep learning algorithms. [NVIDIA News 2014].

In-car software platforms will see a tight competition between Apple and Android, with main automakers committing to one or the other for the infotainment systems of their dashboards. Nonetheless, a number of automobile companies are empowering their own proprietary entertainment systems as well. In the meantime, Automotive Grade Linux is going to move the open source philosophy also in a vehicular infotainment context. To improve the user's experience, a high attention is expected to be given to personalization and context awareness (i.e. the vehicle's adaptability to the behavior and desires of the users).

Millions of connected cars will hit the road in the next months, and they will be placed at the center of the growing Internet-Of-Things scenario. Vehicles will be more and more integrated with devices introduced from the outside, and with users' homes. Prominent OEMs are providing innovations for the integration between cars and homes. Two examples are given by Ford, that is exploring the possibility of integrating the SYNC systems with the smart-home solutions offered by Amazon Echo and Wink [BusinessWire 2016], and by BMW, that is trying to enhance users' experience by integrating all their devices in the "Open Mobility Cloud" [Car And Driver 2016].

Finally, a major effort has to be done to guarantee the security of connected car software, since the integration of infotainment systems with car functionalities, and their openness to third-party applications, can allow malicious actors to take control of vehicles. The "Jeep Experiment" [Wired 2015] of July 2015 (with hackers remotely maneuvering a car with the driver inside), and the hijack of Tesla Model S of August 2015, has made the public attention to automotive vulnerabilities grow. Automakers have to take into account all the possible threat actors in order to allow people to use luxury cars without worries for their security. A serious concern is also linked to data privacy: since cars will likely be uploading enormous amounts of information to the Internet, the driver shall be provided with a full control of the sensible information she would accept to be communicated.

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