Autonomous Vehicles and Smart Mobility Related Technologies

Cristina Olaverri-Monreal *Member, IEEE*

***Abstract*—Smart Mobility is associated with a sustainable mobility performance that in turn affects quality of life. Current technology makes it possible to compile massive amounts of real-time data to optimize the urban infrastructure, consequently improving the efficiency of public transport services, from both user and service-provider perspectives. The analysis of these location-based data enables us to determine which services could be useful for citizens at a certain time, for example, thereby improving citizens' ability to navigate the most efficient routes and modes of travel. Various aspects of technologies that enable smart mobility in cities, including autonomous vehicles are presented in this paper.**

***Index Terms*—Smart Mobility, Internet of the Things, Ubiquitous Sensor Technology, Smart Cities, Autonomous Vehicles.**

I. INTRODUCTION

Transportation, parking and traffic management are decisive aspects in the characterization of Smart Cities. Other factors include for example: information and communication systems; energy efficiency and sustainability initiatives; citizen engagement and empowerment; open data and government transparency; public safety and security [1]. Mobility serves as one of the additional classification categories for Smart Cities that have been defined within the EU project "European Smart Cities" [2] together with: economy, people, governance, environment, and living Smart Cities. To determine if societal needs or technological trends affect this mentioned selection of parameters, it is crucial to investigate the role of the citizens, as future users to find out their needs and guarantee a citizen-friendly living environment. Taking this into account helps prevent unnecessary growth and development of undesirable or useless information and infrastructure, which would only overwhelm and upset citizens and negatively affect their quality of life.

The knowledge resulting from the analysis of massive amounts of data compiled using technology can assist in the creation of extensive social benefits [3]. Particularly, digital technologies derived from real-time data optimize the urban infrastructure, therefore improving efficiency and effectiveness of citizen navigation. The growing trend towards ubiquitous information communication that results from pervasive computing is particularly embodied in today's smart devices, which already integrate a variety of cost-efficient embedded sensors and facilitate the acquisition of data to study mobility patterns [4]. Research related to these location-based data enables us to take a decision about which services could be useful for citizens in order to improve the efficiency of public and transport services.

This paper presents various aspects of technologies that enable a smart, sustainable mobility in cities and is organized as follows. The upcoming section reviews the state-of-the-art and related work in the area of Urban Mobility and Smart Cities. Section III demonstrates the importance of the Intelligent Transportation Systems (ITS) field. Section IV introduces Autonomous Vehicles and portrays their role in Smart Mobility. Concluding thoughts are stated in the final section of the paper.

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C. Olaverri Monreal, is with the University of Applied Sciences Technikum Wien, Dept. of Information Engineering and Security, Höchstädtplatz 6, 1200 Vienna, Austria. E-mail: olaverri@technikum-wien.at

II. STATE OF THE ART AND RELATED WORK

A. Smart Cities

Smart Cities are associated with a high quality of life. Quality of life is determined through several diverse factors that include sustainable transport systems, safety and security, the availability of green open spaces and other basic services. Other less obvious indicators are actively promoted and elevated citizen interaction and social inclusion, which can be embodied by shared public spaces for cultural and sport activities, for example [5].

The European Initiative on Smart Cities aims to support cities and regions in taking ambitious measures to progress by 2020 towards a 40% reduction of greenhouse gas emissions through sustainable use and production of energy [6]. Similarly, the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) intends to develop collaborative and participatory approaches for cities, industry and citizens to improve urban life through sustainable solutions. This includes more efficient use of energy, transport, and Information and Communication Technologies (ICT), thereby reducing overall energy demand and increasing the use of renewable energy sources [7]. There are already over 14 European projects that have their focus in the sectors "Energy", "Transport & Mobility" or "ICT" that resulted from this European Partnership [8]. Energy-related aspects are addressed by 9 of the 14, while 3 cover all the areas Energy, Transport & Mobility and ICTs. In the context of transportation, the European FP7 program already funded projects that addressed sustainable management of urban waste [9] or intelligent urban bus systems [10].

B. Smart Urban Mobility

In the report for the *Sustainable Mobility Project 2.0 (SMP2.0)* within the World Business Council for Sustainable Development [11] the authors described 22 indicators for parameters and methodologies to be used by cities to identify their sustainable mobility performance. Smart urban mobility intersects with several of these important indicators such as congestion and delays, commuting travel time, mobility space usage, access to mobility services, traffic safety, comfort and pleasure, intermodal connectivity and occupancy rate. It additionally connects a range of technologies such as vehicle manufacturing, transport information systems, communications technologies and logistics.
These mentioned parameters and their relationship with Smart Mobility will be further addressed in this paper that expands the individual areas described in [12].

According to [13] European cities have better public transit and a stronger focus on sustainability and low-carbon solutions than other cities in the world. The cities in Europe that in 2014 had developed the most innovative actions related to infrastructures and technologies are Copenhagen, Amsterdam, Vienna, Barcelona, Paris, Stockholm, London, Hamburg, Berlin, and Helsinki. However, there is still room for improvement at a European level aiming at a decrease of pollution and carbon dioxide emissions. For example, several European cities have already started plans to restrict traffic and parking in downtown areas, with interruption of the production of industrial plants, or via speed limitations [14] to alleviate the current high levels of carbon dioxide output.
As an example, the city of Amsterdam is providing its citizens with technologies that ensure a better quality of city life within the framework of the Amsterdam Smart City Project, such as free Wi-Fi and a new optical fiber network. Moreover, "smart grid" technologies for transportation are contributing to a reduction of emissions by guiding trucks to available unloading zones, controlling traffic lights and bridges and providing residents with personalized travel advice [15], [16].

C. Connectivity

To receive the Smart label, cities must rely on broadband connectivity [3]. A concept representing the elements that constitute a Smart City using digital technologies is proposed in [17]. According to the authors, a Smart City differentiates itself from other cities by exhibiting an assemblage of various components for understanding and coordinating urban problems with innovative technologies in an effective and feasible manner. The framework concept covers different dimensions including urban governance and functioning, infrastructure organization, transport, and energy.

There has been a drastic increase in the number of systems which rely upon sensor data collection. This in turn generates a large body of information and sources to analyze. Furthermore, there is an overall spread in the application of digital technologies through the deployment of physical sensors in homes, buildings and cities. This pervasive computing context presents the possibility of designing Smart City applications which base their functioning on intelligent technologies that simultaneously reside in other applications that communicate with each other. This integration of ICT in conventional city infrastructures is part of the strategic initiatives of the international joint projects of the Connected Smart Cities Network described in [18].

The design and application of information and communication technology to create environmental benefits, the so called Green ICT, plays a decisive role in reducing carbon emissions. As stated in [19], communication networks and the related infrastructures that consider energy efficiency could create a 20% reduction of global CO2 emmisions by 2030. Enhanced connectivity through ICT could significantly affect Smart Mobility by reducing congestion, emissions, and resource consumption through an overall decrease in the need to travel [19].

In this context, mobile operators can play a role in four key aspects of smart city services [20]:

- Connectivity: connecting city infrastructure and personal mobile devices to central servers;
- Data aggregation/analysis: combining data from multiple sources to gain new knowledge;
- Service delivery: delivering real-time information to citizens and devices regarding events in the city;
- Customer interface - providing customer support

In recent years a huge amount of work has been dedicated to sensors supported by Internet of Things (IoT). Intelligent displays in appliances as platforms to share information with additional mobile devices, to manage a healthier diet or to save energy in the household are some of the applications based on IoT. But at a citizen level, big expectations have been put into the IoT as technology for an ubiquitous information access via the Internet. The large concentration of resources and facilities that attract people from rural areas to cities [21] is causing a population growth that is making it increasingly challenging for city governance and politics to enact efficient city management. Moreover, the current 54% of world's population that lives in urban areas is expected to increase to 66% by 2050 [22].

There is great potential in the IoT in developing and connecting technologies which assist in improved city management and better quality of life for the growing citizenry. Through the Internet of Things, products can be connected to create more efficient transportation systems. The European Commission predicts that by 2020 devices connected to the internet will number between 50 and 100 billion [23] and will form the base for cooperation frameworks for access to knowledge resources.

A vision of the Internet components, Internet of Things and Internet of Services (IoS) transforming a Smart City into an open innovation platform has been specified in [24], [25]. The authors also present a generic concept implementation

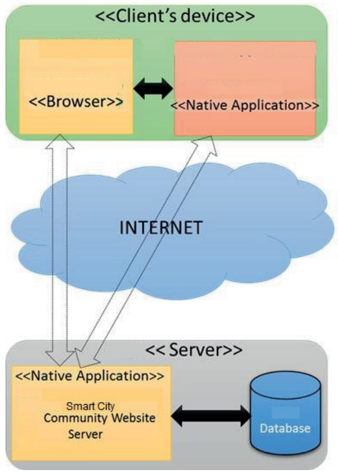

Fig. 1. Client-server architecture to share urban information (adapted from [27])

based on Ubiquitous Sensor Networks.

As the use of IoT to support sustainable development of future Smart Cities entails several difficulties that are related to the various natures of the connected objects, a work was proposed in [26] that described a management framework for IoT. Within this system, objects are represented in a virtual environment. Through the use of cognitive and proximity approaches the authors make it possible to select the most relevant objects to Smart Cities.

D. Collaborative Approaches

Collaborative teamwork based on shared mental models is required to create frameworks for understanding joint work [28], [29]. This work has to be collectively conceived and shared by several users relying on activity awareness. Just such a collaborative approach is crucial in the advancement of Smart Cities, at both local and intercity levels.

Citizen feedback on issues and suggestions for improvement of services [30] are a fundamental requisite for a sustainable, efficient city. Modern pervasive communication technologies make it possible to share widely available information between citizens and public authorities so that a subsequent data analysis can be performed by taking advantage of crowd-sourcing data technologies. Figure 1 shows an example of information client-server architecture to share urban information.

As local and personalized solutions are expensive to develop and maintain, and can affect the mobility route choices left to other road users it is essential to develop frameworks and platforms to share knowledge and best practices. To this end, methodologies that capture data related to citizens preferences and habits help to identify and understand their needs and goals. For example, through measurements to establish relationships between variables such as travel origin and destination and others such as recommended route. In the Smart Mobility cooperative context, the authors in [31] investigated the effect of the number of vehicles and available road capacity on the level of congestion, with a focus on modifying route choices. They studied the relationship between travel demand and driving travel times, and assessed the benefits of different scenarios. In the work, they conclude that social consideration related to routing behavior affects congested cities positively.

III. Intelligent Transportation Systems

Roads are a shared space for people and vehicles. In the same manner that applied sensor technology is fundamental in IoT and IoS, sensors can be integrated into road infrastructure to recognize and monitor a wide repertoire of activities related to the transportation sector. According to [32] the European Commission's "ITS action plan", or action plan for the deployment of intelligent transport systems aims to make road transport and its interfaces with other transport modes more environmentally friendly, efficient and safer. To this end, European standards, for example for the exchange of data, need to be set. Moreover, the EU encourages the use of different transport modes to reduce congestion and greenhouse gas emissions, decrease the number of road traffic accidents and energy consumption.

According to [33] production- and consumption-based emissions that result from cities account for more than 80% of the world's greenhouse gas (GHG) emissions. Some cities, are so badly affected by pollution that their citizens are advised to stay indoors or restrict vehicle use. As a consequence, finding energy supply that directly involve mobility systems has become a priority. A change in the mode of transport, travel route and the integration of real-time information can lead to better average car speed and an improved traffic flow, as it has been shown in Singapore with 27 km/hour, compared to 16 km/hour in London and 11 km/hour in Tokyo [34], [16].

In the context of a more efficient use of energy in the transport sector, the steady integration of electric cars will contribute to a decrease of fuel consumption. Automobile manufacturers, facilitated by reductions in battery prices, offer increasingly affordable vehicles without internal combustion engines. According to the predictions of *Bloomberg New Energy Finance*, 35% of the cars that are sold in 2040 will be electric. It is expected that by 2020 they will represent a more economic option than gasoline or diesel cars in most countries [35]. Despite their rapid growth, plug-in electric cars represented only 0.1% of the one billion cars on the world's roads by the end of 2015 [36]. It is clear that major efforts still need to be made to promote electric driving, which, though considered beneficial for the environment, is not yet widely accepted by the public [37].

A. Mobility Patterns

The monitoring of mobility patterns can be used to study driving behavior for improving traffic flow through a reduction of traffic congestion and an increase in road safety [38], [39]. Mobility patterns are the big-picture sets of information that show people's habits and routes. Therefore, mobility pattern information is crucial in providing personal multimodal mobility services as it can guide technological applications in suggesting travel routes and creating new habits.

Crowd-sourcing data available through mobile devices and processed through cloud-based architectures facilitate the monitoring process to support travel pattern changes based, for example, in new routing recommendations. Figure 2 depicts a scheme to acquiring, storing, processing and analyzing mobility-related data using smartphone sensors. Such an approach permits the users to benefit from additional services, such as recommendation of alternative route paths and feedback related to current driving patterns for a shorter traveling time or fuel savings. Moreover, modification of mobility habits can be encouraged through gamification approaches, awarding commuting users with discounts for certain services if they avoid rush hours or use public transportation. Serious games can additionally modify driver behavior contributing educated drivers in avoiding unsafe actions by using a scoring system [40]. Smartphone technology can also be for example applied to give a good approximation of the vehicle occupancy rate as a parameter for smart mobility.

Urban mobile data makes it possible to develop intelligent mobility concepts in which replacing private vehicle use with public transportation use and a reduction of traffic create an efficient flow of the remaining vehicles, consequently lowering total carbon emissions. The goal is to achieve a balanced optimization of transit use and personal vehicles, for a faster commute and environmental benefits. To this end, improvements in urban mobility have been initiated through planning of routes in real-time. As several factors such as weather, maintenance work, accidents, public events, etc. determine the use of public transportation but also of private vehicles [3], it is important to provide clear and accurate real-time information that allows commuters to make decisions regarding the use of public transportation or personal vehicles, and also to select the mode of transportation that better fits the needs of everyone (Figure 3).

The use of mobile devices in a road context by drivers and VRU is rapidly increasing. In a vehicular context, proper in-vehicle warnings and function location that enhance visibility and reduce the distraction potential has been the design focus by automotive manufacturers for many years [41]. However, this has not been extended to mobile devices that are increasingly being used in a road context, and most mobile solutions tend to neglect the risks related to the influence of mobile phone usage in a situation where traffic needs to be considered [42]. In addition, the basic needs of pedestrians regarding for example routing approaches are not been considered in most of the cases [43]. Therefore, the use of mobile devices is becoming a very prominent safety issue, particularly relevant in urban environments with high traffic density. Pedestrians and other vulnerable road users (VRU) can be supported by mobile applications for use in public spaces or transport in their route choices to minimize potential dangers such as distraction. Vehicle-to-pedestrian (V2P) and pedestrian-to-vehicle (P2V) communication technologies for exchanging information work towards improving road use and safety through warnings for users regarding potential dangers. Research, mostly based on GPS data, has been developed in this field. For example, the authors in [44], [45] developed a system based on wireless pedestrian-to-vehicle communication which was able to issue warnings of collision risk.

Since perception and communication are essential for VRU safety, theoretical models and studies have been performed in real-world environments to test the reliability of several systems. A cooperative system as a combination of both approaches and that integrates the outputs of the communication and perception systems was proposed as the optimal solution by the authors in [46].

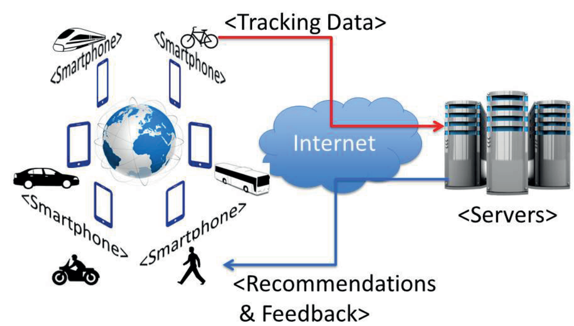

Fig. 2. Scheme for the acquisition, storage, processing and analysis of mobility-related data using smartphone sensors [4]

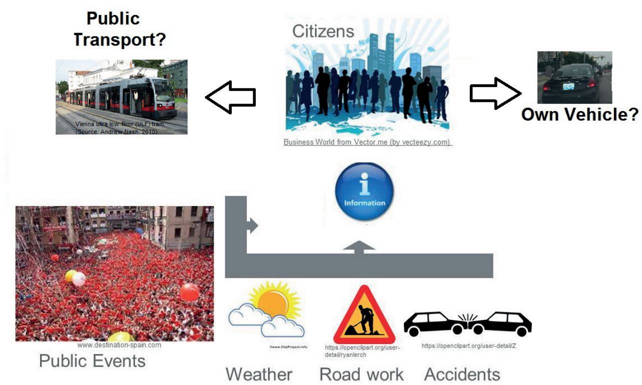

Fig. 3. Selected factors that determine the use of public transportation or private vehicles

Fig. 4. Cooperative driving in which visual data related to the safety distance is provided to the vehicle behind in real-time [50]

B. Traffic Data and Cooperative Systems

Urban traffic data can be acquired through sensors available on road infrastructure, mobile devices or the cars themselves. For example, the authors in [47] deployed Bluetooth scanners along the freeway/arterial network in the road proximity to study and characterize urban traffic conditions. The collected travel time information enabled an effective traffic management, control and flow optimization as well as the basis for improving existing routing algorithms, positively affecting costs related to logistics and reducing the environmental impact.

Exchange of information through cooperative systems that broadcast traffic data is imperative to enhance road safety. To this end, urban environments provide the test bed conditions required to perform realistic experiments with massive amounts of valuable data. This allows for the evaluation of a variety of protocols, as well as interaction with in-vehicle systems and services. For example, within the design and development of the See-Through System [48], [49] experiments under real conditions were performed in order to test potential connectivity issues and data transmission delays using the 802.11p standard wireless communication protocol.

In a joint effort to implement safety and decision-making processes at an individual level, further cooperative approaches can increase the drivers visual awareness, for example of safe distances. Through the stereoscopic capturing and processing of images by rear cameras information can be garnered to determine if the safety distance is appropriate [50]. Figure 4 illustrates the idea.

IV. AUTONOMOUS VEHICLES

Realistic Vehicular Ad Hoc Networks (VANETs) and the related technologies, for example those implemented in autonomous car applications, will change cities as we know them. As stated by the executive director of the car manufacturer Ford, Mark Fields, “2016 will be a revolutionary year for automotive and transport, in which we will see radical advances that will change the way to move”. According to the International Organization for Road Accident Prevention [51], human error is the cause of 90 percent of the road accidents. To alleviate the number of accidents, the introduction of autonomous vehicles on our roads represents an opportunity for increased road safety as the automation will make driver intervention in the control of the vehicle unnecessary (Figure 5).

Other advantages of the use of driverless vehicles will be an uninterrupted traffic flow, energy consumption reduction and road capacity increase through a decrement of the aerodynamic impact on the vehicles, leading to a minimization of the distances between them. This will be ensured by sensors that will control the spaces between vehicles and the observance of the safety distance. Autonomous trucks with automated features have already successfully platooned across Europe to increase environmental, safety and comfort benefits [52].

Autonomous Vehicles (AV) can work as network nodes in a VANET, being thus capable of identifying exceptional situations in which it is difficult to plan appropriate measures (i.e. road works, unforeseeable traffic situations like accidents that result in a traffic congestion or missing map data). Under these circumstances, vehicle control localization and mapping could be conducted based on data available from other vehicles in the same VANET [53]. Alternatively, the control could be relayed back to humans, through an emergency Take Over Request (TOR). Here prediction systems would play a crucial role [54]. Assessment of the driver’s state and the driving environment is essential in promoting road safety in both manual and automatic driving paradigms where the monitoring tasks are either performed by the driver or by the system. In this line of research a cost effective mobile application to measure gaze behavior and analyze road conditions was presented in [55]. The application worked on a mobile smart device in an automatic driving paradigm where a TOR was triggered in case of an unexpected road situation or in a manual driving paradigm to avoid inattentive driving.

It is expected that AV represent more opportunities to develop innovative in-vehicle technology for entertainment or information purposes that will require a cockpit design adaptation and modification of the car controls for more flexibility of movement within the vehicle. In this context, some automotive manufacturers are already performing research on new designs concerning the steering wheel. For example the authors in [56] investigated the effect on the driver of taking over a control request from a highly automated vehicle using a geometrically transformed steering wheel. Results concerning the reaction time when taking over control of the vehicle were discussed.

A complete vehicle interior redesign without a steering wheel or pedals seems unlikely though, as it would impede adequate response to a TOR in an unexpected situation or switching to manual control, which would firstly affect safety and, in addition, User Experience (UX) or joy of use.

The potential boredom and road monotony associated with higher automatism of vehicles might lead to a reduction in driver situational awareness (Table I depicts the levels of automation). This condition will have to be compensated by new ways of prominent and understandable continuous feedback that might, on the other hand, decrease the joy of use. Research in the field is imperative to guarantee an optimum level of automation that is balanced by an appropriately demanding cognitive workload.

It has been shown that perceived usefulness, trustworthiness and ease-of-use have a direct impact on consumers' behavioral in their intention to use a specific tool [57]. It is not yet clear if any reduction in the joy of driving due to automation will be found to be acceptable by those who enjoy driving. Trust also plays a decisive role in the adoption of the new self-driving car technology, as the drivers needs to accept occasional autonomy of vehicle and cede part of their own control. In the same context if the passenger in an automated vehicle is not able to verify the authenticity of the provided information (e.g. in case of information broadcast by inter vehicular wireless technology), it might jeopardize perceived trustworthiness of the technology.

In this line of research, the interaction of autonomous vehicles with other road users has been investigated in several works but until now it has been only based on simulated scenarios or survey studies [58], [59]. However, the authors in [45] performed a field test with driverless vehicles provided with full autonomy notifying pedestrians through a smart phone application that an autonomous vehicle was approaching. The goal of the work was to test if such a message would help pedestrians to develop a trust in the autonomous vehicle technology. The participants in the experiment stated that the application supported them in the verification process of trusting autonomous vehicles as a reliable safe technology, as they realized that it was as safe as a conventional vehicle.

The profile of future AV customers or who will maintain ownership of the vehicles is not yet clear, for example whether they will be private property of the suburban commuter population themselves. Other unknown social and cultural consequences of increased AV usage are topics for future research, for example: could the comfort that AV provides cause an increase in population relocation to suburbs, and lead to environmental problems? If self-driving cars become popular among citizens, and if downsides such as potential hacking exposure or safety concerns are surpassed, their traveling comfort and privacy will seriously compete with the use of public transportation.

It is expected that Autonomous Vehicles will foster the sharing of vehicles without the need of owning them. On the other hand, car ownership is extremely popular among younger people, as shown in the 2015 Continental Mobility Study [37]: of those surveyed 83% of Germans used their own car, while 17% used a family car and only 1% used rental cars or relied on car sharing. In the US the results regarding shared use of vehicles showed that 94% of the participants in the survey used their own car, 5% used a family car and 1% used a rental or car sharing vehicle. Autonomous Vehicles represent an opportunity to redefine individual mobility, as they create more opportunities for car sharing (including ridesharing or car pooling) and, as has already been observed, can reshape our current societal business organization by enabling new business opportunities.

TABLE I

LEVELS OF DRIVING AUTOMATION FOR ON-ROAD VEHICLES. ADAPTED FROM [60]

Autonomy Degree	Description	Examples
1. Driver only	Vehicle entirely under human control but might have some automated systems.	Cruise control, electronic stability control, anti-lock brakes.
2. Driver assistance	Steering and/or acceleration are automatic but the driver must control the other functions.	Adaptive cruise control: distance to leading car maintained; Parking assistant: steering is automated. Driver controls accelerator and brakes.
3. Partial autonomy	Driver does not control steering or acceleration but is expected to be attentive at all times and take back control instantaneously when required.	Adaptive cruise control with lane keeping. Traffic jam assistance.
4. High autonomy	Vehicles are able to operate autonomously for some portions of the journey. Transfer of control back to the human driver happens with some warning.	Prototype vehicles.
5. Full autonomy	Vehicle is capable of driving unaided for the entire journey with no human intervention; potentially without a human in the car.	None.

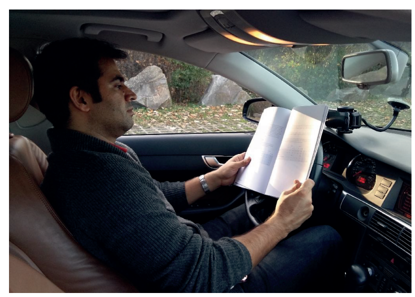

Fig. 5. Autonomous vehicle passenger that does not require overseeing the driving task.

A lower number of cars per household would be necessary if autonomous vehicles are used, as they could be called through mobile applications and move to the location where they are needed. They will also demand fewer parking lots and require reduced road space, as they allow for narrower city lanes and therefore more room for pedestrians and green spaces. This in turn will count towards an improvement in quality of life in cities.

Whether road redesign will be required (i.e. by adding dedicated lanes for AV) or adaptation of infrastructure such as marking for road signals, or even VRU marking for better recognition, is necessary, is not yet clear; but in this case it will represent an opportunity for improvement.

V. Conclusion

This paper gives an overview of different aspects and factors that determine the qualification of "Smart Mobility". Even if a large number of projects and initiatives have been started to provide citizens with efficient and effective services, there is still room for improvement, particularly concerning environmental benefits. Applied sensor technology is fundamental in sharing knowledge and fostering communication, as well as in gathering feedback from citizens, in particular to facilitate the acquisition of data to study mobility patterns. Environmentally friendly, efficient and safer road transport that fosters multimodal transport through the exchange of data, is a crucial objective to reduce congestion and greenhouse gas emissions. To this end, sensors can be applied into road infrastructure to recognize and monitor a wide repertoire of activities related to the transportation sector. Autonomous driving will definitely affect current mobility and the driving experience. It will have implications for regulatory, social and economic sectors, as well as in urban planning and the various factors affecting smart mobility.

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Cristina Olaverri Monreal graduated with a Masters degree in Computational Linguistics, Computer Science and Phonetics from the Ludwig-Maximilians University (LMU) in Munich 2002 and received her PhD 2006 in cooperation with BMW. After working several years in different European countries and in the US, both within the industry and academia, she currently leads the Competence Team "Intelligent Technologies in Smart Cities" at the University of Applied Sciences Technikum Wien, Austria. Her research aims to minimize the barrier between users and systems in complex, dynamic scenarios that are critical to decision-making processes, such as driving a vehicle and innovative forms of mobile and ubiquitous interaction approaches to human mobility. Dr. Olaverri is a member of the IEEE Intelligent Transportation Systems (ITS) Council Executive Committee, Vice-president of Educational Activities, and a member of the IEEE ITS Board of Governors (BoG). In addition, she serves as chair of the Technical Activities Committee on Human Factors in ITS and associate editor of the IEEE Transactions on ITS and ITS Magazine.