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Innovative Vehicular Technologies for Urban Mobility: A Smart City Perspective

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Abstract- The term smart city has recently become recurrent in discussions about the development of new urban models that use technological innovations to become economically, socially and environmentally efficient. From the perspective of transport, this theme translates into the search for smart mobility, through the introduction of new vehicular technologies (connected and automated vehicles) and disruptive transport means. These innovations are in line with sustainable development, as they have the potential to promote the efficiency of displacement, aiming to improve accessibility and mobility, and minimize the negative impacts caused mainly by congestion, pollution and road accidents. Connected and automated vehicles have the potential to affect profoundly on energy efficiency and reduce its consumption, and decrease of frequency and severity of traffic accidents. With sequential increases in productivity, and decreases in production, operation and maintenance costs, these vehicles are already a revolutionary technology. The aim of this paper is to present an overview of current trends and vehicular technological innovations in the search for smart mobility within the context of smart cities.

Keywords- *Smart City, Connected Vehicles, Automated Vehicles*

I. Introduction

Smart city has recently become a recurrent theme in discussions on the development of new urban models, which rely on innovation and technology for higher economic, social and environmental efficiency. The expression smart city was coined in the early Nineties, meaning the shift in urban development through technology, innovation and globalization [1]. The concept of smart city, as a means to improve the quality of citizenship, is increasing in importance for both public policy and decision makers [2]. However, there is no consensual definition of what a smart city is. Dozens of different smart city definitions can currently be found in literature [3]. Reference [4] asserts a smart city consists in the utilization of infrastructure networks to improve economic and political efficiency, to improve social, cultural and urban development. References [3 and 5] claim that smart cities represent a conceptual model of urban development, based on the utilization of collective human capital and technology for the development of urban aggregations. Reference [6] affirms that a city is smart if it employs information and communication technologies to improve its livability by becoming the quality of life of its citizens better; developing the local economy; enhancing urban infrastructure systems such as transport and traffic, electrical grid, water supply, waste management, and etc.; promoting environmental awareness; and facilitating and speeding interaction with government authorities.

Then, the purpose of smart cities is to provide the highest possible quality of urban life to their citizens. Smart cities and communities focus on the integration of energy, transportation, information and communication technologies (ICTs), which are also recipients of close attention and financial investment. So, a city is considered smart when it fosters inventiveness and creativity of its citizens. The notion of smart city is intimately related to knowledge economy – the usage of knowledge to generate tangible and intangible value, to change the spatial patterns of urban agglomerations and to knowledge-based urban development. [7-10].

From 2004, the smart city concept was adopted by several technology companies, such as Siemens, Cisco, and IBM, referring to the application of complex information systems to integrate urban infrastructure operations and services, such as buildings, transportation, power, water supply and public security. Since then, the concept has evolved to mean forms of technology-based innovations to plan, develop and operate cities The most recent interest in smart cities may be attributed to strong concern on sustainability, with the emergence of connectivity technologies - such as mobile devices (e.g. smartphones), semantic web, cloud computing and the Internet-of-Things (IoT) - fostering user interface with the real world [1and 11].

Smart cities are the core of mobility innovation development, since mobility is the essence of any city, enabling the movement of people, goods, information, and ideas, and allowing opportunities for social interactions. Mobility is what makes a (smart) city livable and an attractive place to live and socialize. So, a smart city presupposes a smart mobility. Thus, in the smart city topic, vehicles used in the urban transportation systems must reflect such world trend by contributing to the search for smart mobility. Mobility is a characteristic of the individual, since it means the capacity of people to move from one place to another and it depends mainly on the availability of different transportation modalities. In fact, that concept must be broadened because mobility encompasses not only the act of travelling (moving), but also – even more important – the capacity of people to choose when, where and how to travel, consciously using information adjusted to optimize their trips, within time, space and cost constraints. So, smart mobility is evolving and refers to the usage of information and communication technology (ICT) in transportation to improve traffic, whose related urban life aspects are transportation infrastructure, services and logistics inside the city. The most important objectives of smart mobility are: reduction of pollution (both atmospheric and noise), traffic congestions, increase people's safety, improve traffic speed and reduce cost of trips [12-16].

Therefore, smart cities, as shown in Fig. 1, must optimize usage and exploitation of tangible (transportation and logistics infrastructure, energy distribution networks, natural resources, etc.) and intangible assets (human resources, intellectual and organization capabilities from state bodies, etc.). However, to implement such undertakings, significant financial investment and time are required, on technology development, machinery acquisition and mainly human resources qualification, capable of generating innovation and operating the system [2].

Figure 1: Smart cities and their systems. Source: authors

It is common sense electric vehicles (and electromobility in general) are – and will be even more in a near future – a fundamental component of intelligent mobility in smart cities. Also, the advent of sharing of vehicles (car, scooter, bike, etc.), ride sharing (carpooling, van pooling, etc.), on-demand mobility services (ride sourcing, e.g. Uber; ride splitting, e.g. UberPool), mainly using electric vehicles, are essential innovations for further development of smart urban mobility [17-19].

In the academic literature, several studies search alternative solutions for the challenge of sustainable transportation in large urban centers– integration and balance of transportation, land use and environmental policies – contributing to economic and social welfare without exhausting natural resources or harming the environment and human health [20]. The principles of sustainable transportation, within the context of smart mobility, may be achieved, for instance, with the introduction of shared modes of transport backed by modern technologies such as intelligent vehicles (connected and automated), aiming to improve accessibility, mobility and road safety, in the pursuit of social equality and moving towards smart cities. Hence, technological innovations in the design and development of intelligent vehicles, especially with electric propulsion, are important to those users who demand agility, safety, efficiency and control of their daily trips. Such innovations propel and strengthen smart mobility initiatives, increasing transport options in smart cities [21-23].

For those reasons, the present paper presents a comprehensive overview about new automotive technologies and their role in the mobility of smart cities. The objective of this article is to structure and provide an updated general view of current trends and technological innovations related to intelligent vehicles in the context of smart cities.

Since the purpose of this study is to get a broader understanding of the current state of research on smart cities from an "intelligent vehicle" perspective, the search method was restricted to technical and academic literature, with the investigation of initiatives from both the transportation sector and the automotive industry. Scientific literature review included the most relevant published papers in the last years, and also encompassed academic books, scientific reports and technical information about emerging technologies.

The article is structured in the following way: after the introduction, the next chapter describes connected vehicle technology, followed by automated vehicles. A further section discusses the findings and another concludes.

II. Methodology

The methodology adopted was the Snowball Research that consists of identifying scientific papers that explore the theme "smart cities" and its innovative technologies in smart mobility, and also intelligent vehicles. Thereafter, one paper leads to another one, which in turn provides a third article, and so on. In this research, it was used the most relevant studies to find significant papers cited in, that lead to additional researches, and the process continues.

This systematic bibliographic study reviewed some innovative urban mobility technologies present in smart cities, mainly those related to the development of connected and automated (also known as driverless) vehicles. A literature review was undertaken in academic and scientific databases, such as Web of Science, EBSCO Discovery Service (EDS), CAPES/MEC, Google Scholar, etc. Some of the most important books and articles published in the literature over the last years were used to conduct this research.

III. Connected Vehicles

Sustainable development in the transportation sector seeks to promote practices that diminish energy consumption and pollutant emissions, from reduction till total suppression of non-renewable natural resource usage. The smart city paradigm assumes conscious, balanced and sustainable exploitation of energy resources. An example is smart grid in the power generation and distribution sector, a modern infrastructure network conceived to improve the efficiency, reliability and safety, integrating renewable and alternative power sources through automated control and communication technologies. Smart grids, for their turn, propel new technologies in the automotive industry, like the development of electric vehicles (EVs). It provides the opportunity to test not only new technologies and services, but also the interactions and interfaces among them, concerning energy efficiency (smart grid), people's mobility (smart mobility) and new vehicle concepts (EVs), which are key concepts for the automotive industry in the 21st century [24-25].

The need to improve traffic conditions, user safety and comfort in the transportation systems and to reduce operational costs in the traffic system, lead to the introduction of several automation and communication systems in vehicles, which can be explored for the development of new data sources and control methods. In a highly competitive setting, a significant number of automobile manufacturers, software and hardware developers are facing a challenge to supply innovative solutions for the new generation vehicles. Current vehicles are expected to release some of the operational stresses from users in their trips, providing attractive infotainment functions. But they must also meet ever more stringent safety and reliability standards [26-27].

In such scenario come connected vehicles (CVs), derived from the intelligent transportation systems (ITS) and referring to driving and usage automation technologies. CVs meet the need for new transportation solutions on energy efficiency (mainly fuel), safety, efficient mobility and accessibility and bring new opportunities for specialized labor and clean technology businesses. CVs interface on three levels: (i) vehicle-to-vehicle (V2V), (ii) vehicle-to-infrastructure (V2I and its reciprocal, I2V), and (iii) vehicle-mobile devices (V2X, e.g. smartphones). CVs are capable of wireless accessing and sharing information with other vehicles and the urban infrastructure in real time, through DSRC (dedicated shortrange communications), V2V, V2I, I2V and V2X protocols. Fed by data from the surrounding environment, CVs may adjust their movements in coordination and synchrony with other vehicles and a traffic control system, enhancing safety, energy efficiency and user mobility [28-33].

Table 1 presents possibilities for the interaction of connected vehicles in the present development stage, which is basically an information exchange platform of the vehicle with the external environment - through both local wireless networks and the Internet.

TABLE I. CONNECTED VEHICLE CHARACTERISTICS

Interactions	Functions
Vehicle-to-Vehicle (V2V)	Vehicle interacts with other vehicles
Vehicle-to-Infrastructure (V2I)	Vehicle interacts with traffic infrastructure Vehicle interacts with traffic management and operations center
Infrastructure-to-Vehicle (I2V)	Infrastructure and/or management and control center interacts with vehicle
Vehicle-to-Device (V2X)	Wireless communication with any device

Source: Adapted from [28].

Among connectivity applications, safety is a highlight, allowing users to scan the surrounding environment for potential hazards and danger. They offer the potential to reduce both the frequency and severity of traffic accidents. For instance, users can be warned about the proximity of school areas, tight curves (small curvature radius), unfavorable weather conditions (which can affect both visibility and pavement surface friction), collision risk (sudden braking of vehicle in front) etc. Vehicles may also be warned about bicycles and pedestrians, hence increasing safety of non-motorized users [32].

To enhance CV mobility, information from thousands of users is transmitted (almost always anonymously) in real time to the transportation control center. The information may be used to monitor and manage the system, to coordinate and to synchronize traffic signals, operations or even to send service and emergency assistance staff, when needed. Supplying real-time traffic and weather information to users may support their decision-making, for instance, on choosing alternative routes, transportation modalities or travel time. Those decisions may bring higher efficiency on transportation costs and environmental impact, by reducing energy consumption and emissions. V2V and V2I communications can also enhance traffic flow, by managing vehicle speed and optimizing traffic stops [32].

The so-called in-vehicle technologies refer to interaction of mobile personal devices and on-board vehicle infotainment and monitoring equipment (V2X). Management applications support operational cost reduction and facilitate vehicle usage (e.g. dynamic vehicle servicing, with diagnosis and prognosis of component or subsystem potential failure, repair or replacement need and preventive maintenance). V2X interaction provides entertainment (for example WLAN – wireless local area network – hotspots, audio and video streaming, social media integration and smartphone interface), user well-being (it affects comfort and driving capacity: fatigue detection and medical assistance call systems) and home integration functions (integration of vehicle with the user's home, like domestic climate, illumination, safety cameras and warnings control) [28]. Fig. 2 shows some functions of connected vehicles.

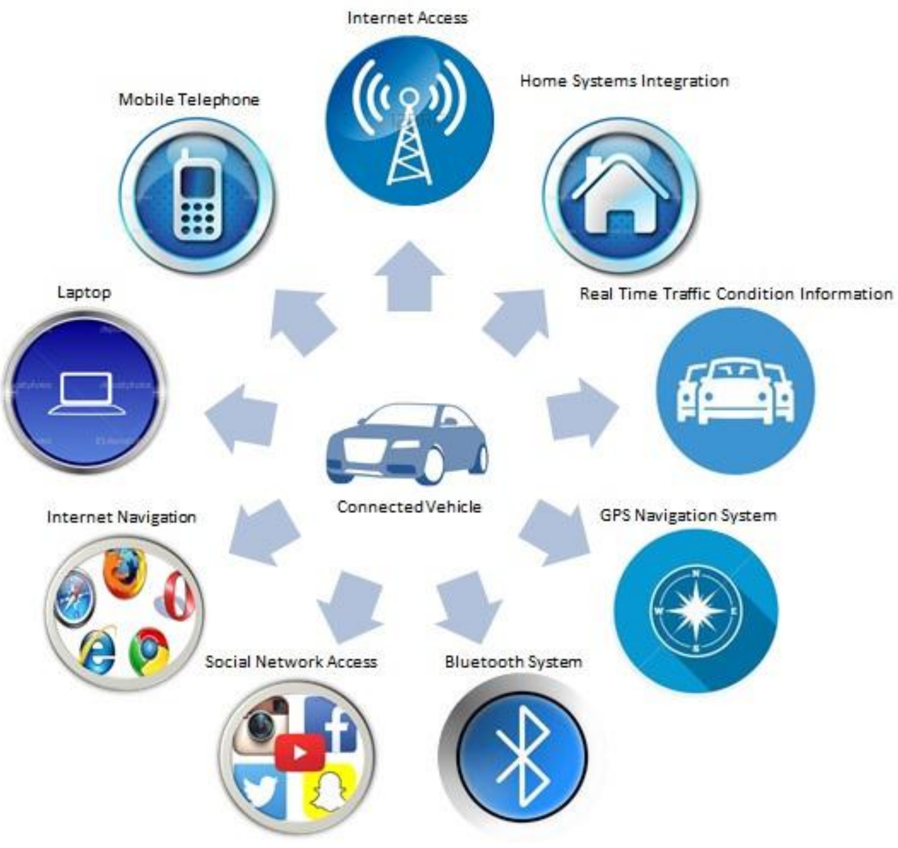

Figure 2: Connected vehicle functionalities. Source: authors

However, the poor wireless connection quality in some regions, and the movement of the vehicle itself, are significant challenges to data flow. The current IP (Internet Protocol) model does not perform perfectly in extremely dynamic environments and, in most cases, it is not capable of precisely locating vehicles in the traffic network. Research is pointing to technologies such as named content retrieval, innate multicast support and in-network data caching, to meet those challenges. Interoperability as standard architecture on vehicle applications, together with emerging computing and network paradigms are being debated as future research venues [34].

The speed of incorporation of new technology on transportation systems is high, especially concerning: (i) user/transportation modality, with real-time information on routes, travel time, traffic volume, warnings etc. (e.g. Moovit, Waze, Uber, etc.); and (ii) user/vehicle, with on-board equipment for connection (Wi-Fi Internet), wireless communication (Bluetooth), multimedia systems, GPS (global positioning system), voice command (hands-free devices), heads-up displays (projection of images on the vehicle's windshield with driver information – such as speed, fuel level, engine revolutions, tire pressure, time), and etc. Reference [35] asserts the importance of information transmission for intelligent navigation in the urban transportation network. Vehicles can play the role not only as traffic information users but also as gatherers, through sensing equipment. So, a large volume of traffic information can be shared among vehicles, and an information network may be created. Although there is still no such fully accomplished and shared network, the topic has received plenty of attention from both scientific and engineering fields. Several communication protocols are being investigated to establish a future "vehicle internet", to efficiently transmit high-frequency data on traffic and vehicle conditions.

Recent technology advancements impact traffic safety, as they pose new challenges to user attention and there is an on-going discussion on regulation of device usage, both personal (smartphones, tablets) or vehicle integrated (multimedia systems, interface devices such as gauges, switches and controls). Distraction from device manipulation is an increasing cause of accidents. Hands-free and heads-up systems offer obvious advantages in safety, as they allow users (especially drivers) to interact with on-board equipment without taking their eyes off the traffic and surrounding environment to the vehicle interior, reducing distraction [36-37]. Connected vehicles provide safety items beyond legally required equipment (for instance, in Brazil, those are regulated by Federal Law; items such as seat belts, front airbags, head restraints, anti-locking brakes, etc.). Some examples of safety devices in connected vehicles: parking assistance with rear-view cameras and blind spot sensors, digital rear view mirrors, hydrophobic glasses, fatigue detectors with lane keep assistance (keeps a vehicle trajectory and warns the driver through buzz and small intensity vibrations), automatic pedestrian detection (warning and braking), this device significantly enhances driver's reaction time, by shifting from an unexpected to a predicted event), and so on [38].

Reference [39] assesses connected vehicles may support speed control technologies, for instance variable speed limit (VSL), by enhancing overall system performance and stabilizing the traffic, decreasing delays and managing network bottlenecks, which generate vehicle queues (stochastic approach – details in [40-42]). VSL, originally developed to improve safety, has emerged as a promising method to mitigate system capacity overload. The strategy consists in trying to streamline the speed of vehicles to create a homogeneous and stable flow, effectively augmenting capacity and critical density. Several empirical studies sustain connected vehicle VSL, by reducing speed differences among vehicles, is capable of fostering a more uniform lane usage, increasing fluidity, reducing queues and hence traffic jamming [39].

There is no doubt safety is fundamental to assure high-level availability and integrity of smart city services to citizens. Although complexity of smart cities is increasing and evolving continuously, traditional safety measures and network management tools are unable to handle an ever-increasing quantity of vehicles and unending updates on forwarding rules. Therefore, vehicles are becoming the next frontier to IoT-based platforms and services. Connected vehicles provide the potential for more efficient and sustainable transportation systems, an important social challenge. In the smart cities, connected vehicles may evolve in a highly dynamic and complex environment, which shapes drivers' decisions in critical situations. They are widely accepted as precursors of smart vehicles, which will allow safety applications and real-time information provision for drivers, passengers and pedestrians. So, connected vehicles are not an end point of the process but evolving detection, storage and computing resources, which may be orchestrated with the urban infrastructure to improve mobility [43-45].

IV. AUTOMATED VEHICLES

Technology innovations may lead the transition to intelligent mobility, through the development of automated vehicles evolved from connected vehicles. Connected and automated vehicles are two distinct but related advancements in innovative transportation technology. A vehicle can be connected but not automated, automated but not connected, neither or both. Automated vehicles are becoming a reality in the United States. By June 2015, seventy-seven automated vehicles (automobiles and buses), from eight manufacturers, were authorized by the California Department of Motor Vehicles to be submitted to experiments and tests. Those projects are characterized by extensive cooperation among public and private entities and they are looking towards smart cities [46-47].

Automated vehicles are equipped with cutting edge technology that enables them to operate with little to no human assistance. They are fitted out with cameras, sensors, radar, lidar (image sensing), GPS and computer vision to sense their surroundings to drive themselves. It is possible because these devices scan the environment and surroundings, and detect obstacles and signage, so the vehicle can "react" as the situation dictates, controlling the steering mechanism, accelerator and brakes as required. The Society of Automotive Engineers (SAE) defines six levels of automation, as presented in Table II. This standard is adopted by the National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation, and it is also adopted by major stakeholders in the automotive sector [47-49].

TABLE II. SAE J3016 – LEVELS OF AUTOMATION

	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Human intervention in driving the vehicle	Someone drives whenever the support features are engaged, even if the driver's feet are off the pedals and he/she is not steering			No one drives when the automated driving features are engaged, even if he/she is seated in "the driver's seat"		
	Someone must constantly supervise the support features; he/she must steer, brake or accelerate as need to maintain safety			Someone must drive when the features requests	The automated driving features will not require that someone to take over driving	
	Driver Support Features			Automated Driving Features		
Features	Features are limited to providing warnings and momentary assistance	Features provide steering OR brake/ acceleration support to the driver	Features provide steering AND brake/ acceleration support to the driver	Features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		Feature can drive the vehicle under all conditions
Example features	Automatic emergency braking Blind spot warning Lane departure warning	Lane centering OR Adaptive cruise control	Lane centering AND Adaptive cruise control	Traffic jam chauffeur	Local driverless taxi Pedals/ steering wheel may or may not be installed	Same as level 4, but feature can drive everywhere in all conditions

Source: Adapted from [49].

The introduction of automated vehicles requires structural changes in: the city road network, such as incorporating IoT concepts, intelligent transportation systems – ITS, and user behavior - especially concerning respect to traffic rules and choice of more efficient transportation modalities. The last few years have brought a race to develop the so called intelligent self-driving vehicles, taking them to streets and roads, as the well-known Google autonomous vehicle (formerly the Google self-driving car project, now known as Waymo) developed in 2010. Those vehicles are fitted with artificial intelligence and robotic technology, are designed to efficiently and safely navigate through city streets and roads, detecting and processing relevant surrounding information, minimizing traffic delays and accidents without human assistance. However, currently, there are no fully automated vehicles on the market (levels 4 and 5 of automation – see Table II). But, there are vehicles that include some connected and automated features which allow them to operate somewhat autonomously, but still require some driver intervention (varying automation level from 0 to 3 -see Table II) [47; 50-53].

The development of automated vehicles is a key research effort of both the automotive industry, and mobility and robotics research centers. Automated vehicles rely on extensive hardware and software integration technologies, high level project management, sensor and data gathering technology, motion control algorithms and communication devices (V2V, V2I, I2V and V2X – see table I). All those elements are continuously evolving and are being constantly rethought for specific applications, especially on detection standards and error and failure tolerance. Those developments seek higher efficiency and safety, and decrease on the cost of automated vehicles. Aspirations for automated vehicle technology's contribution to solve large scale transportation problems, such as traffic jams, emissions and land use/land cover, are high. However, there is still a long way to study, understand and clarify these contributions, as they rely on the design of the integrated service itself and the environment in which it will be deployed [54].

Reference [55] asserts that automated vehicles provide the potential to improve traffic safety and traffic flow, among other benefits. From the academic point-of-view, the systems related to the automated vehicle are an interesting challenge to the understanding of how to explore them in an efficient way. One topic that has called attention is how to find the best route – among several – from a given site of origin (O) to a destination (D), considering varying levels of traffic load and travel times: the "OD problem". Many researchers [35; 56-58] have been studying the OD problem and have developed mathematical models seeking optimal routes in a computationally efficient way. As it is known, in a congested environment, the best route is not always the shortest. So, parameters such as travel time and running costs must compose the model to choose the optimal route. The fastest but less costly route is sought, within rigorous safety parameters, trying to eliminate human error.

According to reference [57], a particularly attractive paradigm is emerging: an automated vehicle fleet to supply on-demand services to customers – automated mobility on-demand (AMoD), using self-driving vehicles for public transportation (taxi, bus, car sharing etc.). Reference [59] predicts AMoD is the future of mobility in urban transportation systems and is one of the major sectors for the large-scale development of automated vehicles (the other being automation of private vehicles). For reference [42], shared mobility with electric vehicles and AMoD systems are a promising alternative to mitigate serious transportation problems, such as emissions, congestion, lack of parking space, and low occupation rates of private vehicles. Reference [41] presented the case study of AMoD systems already in place in New York and Singapore, and concluded those systems – still in their infancy – have the potential of being less costly and more convenient than conventional systems. However, more time and studies are needed to design efficient and coordinated algorithms for AMoD systems, inserted in a multimodality transportation network, and to fully evaluate the economic, social and environmental benefits associated.

The automated vehicle technology is still consolidating and maturing. More of such vehicles will be on streets and roads in the near future. Smart cities are gradually incorporating automated vehicles in their intelligent transportation systems. Automated vehicles may respond instantly to alert imminent danger situations with high efficacy and flexibility. Therefore, the introduction of automated vehicles in the transportation system, especially in large urban centers, presents an opportunity to enhance traffic safety, by making the driver intervention on vehicle control unnecessary. Other advantages are uninterrupted traffic flow, energy consumption reduction, and road capacity increase [60-62]. Reference [12] affirms that the use of the new technologies in intelligent vehicles has the potential to reduce fuel consumption by 2–4% (2647 billion barrels of oil) and cut greenhouse gases by 279 million metric tons each year for the next ten years only in the United States. Besides that, intelligent vehicles can reduce travel times by a third (enhancing traffic fluidity), improve safety (reducing road accidents by 87%), and reduce the number of required parking spots by 44%.

V. Discussion

The main purpose of a smart city is to employ information and communication technologies (ICT) to improve citizens' quality of life in many aspects, such as economy, environment, transport, health, education, and so on. So, studies and researches about "smart cities" has been including Internet of Things (IoT), Information Systems (IS), computer science, and several engineering disciplines. For a city to be considered smart, its systems and services (transport, energy, healthcare, water and waste, etc.) must be smart too, and this can be reached through effective use of innovative and disruptive technologies. Intelligent vehicles (connected and automated) are expected to help smart cities in managing issues related to urban mobility, traffic safety, energy consumption, and coupled with transport electrification, greenhouse gas (GHG) emissions [6; 63-64].

According to reference [63], due to the current development of advances in vehicular technology, intelligent vehicles have potential to provide a promising future for smart cities. Their capabilities and functionalities, coupled with other technological advances, such as IoT devices, smart grid, cloud computing, and etc., play a decisive role in enhancing the welfare of smart cities citizens, as well as environmental benefits. In light of the foregoing, it is possible to extract some findings on how the automotive industry and the development of vehicular technologies can contribute to sustainable transportation, especially in the market insertion of intelligent vehicles (electric powered connected and automated vehicles). Additionally, connected and automated vehicles have potential of generating deep effects on consumption decrease and efficiency increase of energy, and also enhance road safety. With additional increases in productivity and decreases in production costs, operation and maintenance, those vehicles present themselves as a potentially disruptive technology.

Reference [65] highlights the fact research on connected and automated vehicles points towards a future improvement in urban mobility and traffic safety. Emerging automotive technologies are designed to detect, make judgment on external environment (like traffic signals, other road users, traffic density etc.), and take action. However, such judgment depends on adequate performance of cameras, lasers, sensors and scanners, which compose the technology. It should be accentuated connected vehicles – automated vehicles moreover – are among the most advanced inventions on vehicle automation technology, and are still in relatively early research and development stage, with several on-going experiments. Studies seek to improve the technology, contemplating foreseeable associated risks, such as detecting other vehicles and people, mainly vulnerable users of the transportation system (pedestrian, bicycle riders and motorcyclists) [66], and external interface designs, with decision and action protocols to interact with traffic and network infrastructure. However, those same studies reveal automation cannot yet perfectly replace human drivers.

Therefore, emerging connected and automated vehicles have the potential to improve traffic safety conditions, by contributing to reduction in quantity and severity of traffic accidents, by eliminating – or at least minimizing – human error. Some benefits provided by such technologies are increase in road capacity, safety, comfort and productivity, related to the inclusion of new groups of users, like seniors and young people, as well as optimized costs of movement, allowing better overall traffic system management [67-68]. However, as reference [69] warns, due to the lack of real-life historical data on connected and automated vehicles (which can coexist with conventional vehicles on varying proportions), quantifying the effects on safety is a challenging task, which is not properly covered by literature. According to those authors, traffic safety can be significantly improved by reduction of traffic conflicts, even with relatively low market intake rates. More specifically, traffic conflicts are estimated to be reduced by 36%, 73%, 93% and 94% for connected and automated vehicle introduction rates of 25%, 50%, 75% and 100%, respectively. But the process to introduce a new technology is not always fast and smooth. Many significant innovations do not meet user requirements and may be abandoned before market launch. Major obstacles to conquer a market space are not only technology issues, but also lack of acceptance and receptivity to new ideas.

According to reference [70], although automotive original equipment manufacturers and ICT (information and communication technology) companies are developing and showcasing connected and automated vehicles, true autonomy will not happen in the near future, partly due to (lack of) technology systems readiness, but also due to ethics, safety, governance, and regulation issues related to the implementation of road transportation autonomy. However, advance in mobile telephony networks, positioning satellite networks, communication networks and cloud computing, combined with increases in data availability (big data), allied to reduction in costs of retrieval, storage and manipulation, offer a very real possibility of connecting vehicles among themselves (V2V) and to the smart city network (V2I and I2V), as part of the Internet-of-Things (IoT). Data generated and connected from CVs and AVs, when combined with other types of information, through intelligent transportation system platforms, may provide valuable knowledge to government agents, traffic operators, city managers and others. But many issues will still have to be faced for a wide implementation of an IoT truly connected to transportation and other city systems.

However, that same potential could be interpreted as a threat to the traditional automotive industry and, hence, to the consolidated transportation sector in large urban centers. The new generation of vehicles, be them for individual usage, shared or public, is already a reality and have the power to change the relationship among users and administrators, on both existing infrastructure and service offer. Given that situation, the automotive industry will need to adapt and evolve to meet incoming trends. As reference [71] asserts, personal mobility is facing three large and potentially disruptive innovations: electrification, shared mobility and automation. The larger disruptive power comes from a combination of the three – electric automated shared vehicles. Although shared mobility per se may not have the potential to really disrupt the transportation system, electrification and automation should lead to a more sustainable direction. Technology and innovation by themselves are not enough to create a new sustainable transportation system. Regulation is also necessary.

That discussion reflects uncertainty about the future of both automotive market and mobility patterns. Several studies point to shifting trends on personal vehicles, due to innovations in shared mobility, connectivity and automation. No doubt, it is a topic that involves several community agents, including automobile manufacturers, researchers and urban planners. In truth, nobody knows the answer. But there is a series of innovations with potential to modify mobility as we see today, with consequences to the transportation system, energy system and city development.

VI. Conclusion

Thereupon, it is fundamental to incorporate research on technology innovation associated to transportation modalities to the study of intelligent mobility and its role in smart cities. Among those innovations, connected vehicles and their evolution to fully automated vehicles have been discussed and received attention from researchers, technicians and users of urban transportation systems. The introduction of technology advances in all aspects of everyday life is a reality: smartphones, smart TVs, IoT, etc. The same applies to city management, from the moment they incorporate concepts such as smart grids, smart data, smart services, etc., becoming a smart city. One of the protagonists in that new paradigm is the transportation systems. New transportation modalities, noticeably shared mobility, proliferate in the urban space, like car sharing, bike sharing, carpooling and the so-called TNCs (transportation network companies) – an emblematic case being Uber, and are revolutionizing urban mobility in an unprecedented way.

Technology innovation on vehicles and their interface with urban mobility (especially shared modalities and public transport services) is very pertinent to the question of urban management, to the extent that it debates how intelligent mobility can contribute and influence the advent of smart cities. The role of technology innovations on urban management focuses on exploration and understanding of urban systems. They may use new and vast data coming from technology resources like intelligent vehicles, which continuously receive, process, generate and send information and may even retro feed the model to keep it updated and constantly evolving.

That scenario presents great potential for research and applications to improve city management, especially smart cities. Among those applications are: development of dynamic city resource management strategies; theoretical knowledge acquisition; identification of urban patterns and processes; strategies for civil society engagement and participation; public policy innovation, planning, conception and analysis. Therefore, urban management would move from a model of data scarcity and gaps to one with large volume of real time data coming from the transportation system, with the promise of improving our understanding of urban systems, processes and contextual peculiarities and local experience.

Hence, the introduction of technology innovation on vehicles is essential to keep pace with behavior change from some of transportation users, which demand agility, safety and control of their trips, as well as real time information on traffic conditions, travel time, route choice and assertive prediction of costs. The topics in the article are relevant to the extent that they characterize a trend in the automotive market to meet the aspirations of a still small portion of transportation users – due to still high cost – but which tends to grow in the next few years, even in low and middle income markets.

The next steps of the deployment of intelligent vehicles depend on how city leaders can seize a number of opportunities to leverage new technology innovations to facilitate transportation services design and delivery, improve public safety and promote local and regional economic development. By making minute changes to infrastructure and policies today, counties can prepare themselves to be at the forefront of the mainstream application of connected and automated vehicle technology.

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