Vehicle-to-Person Interaction: A Survey

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Abstract: Our society requires the usage of roads and highways, among others means, to move a high amount of objects and living beings every day. Therefore, it is very challenging to preserve the safety when fast and powerful vehicles have to share these crowded public ways with slow and vulnerable subjects. Fortunately, the trend is that regulating authorities are introducing technological advances on new and existing structures, so that automotive vehicles and other users of public ways can coexist together, with a certain level of safety.

In this work, we make a survey of the previous situation, focused on the case of the relationship between pedestrians and automobiles, and we present the current technologies available in this field of research.

Keywords: Vehicular Network; Intelligent Transportation System; WAVE; V2V; V2I; V2P; V2X; Vulnerable Road Users.

1. INTRODUCTION

History is strongly related to efforts to supply solutions to common problems of human beings. There are plenty of examples: the invention of fire, wheel, trading, cities, etc., sought to make human life more comfortable. Cities are a remarkable invention that changed life drastically over the planet, bringing comfort and safety to their residents. Living in a city carries sustainability problems too, although not only limited to urbanization, but rather as the results of poor exploitation of urban aspects [1].

Similarly, while transportation evolved from riding tame animals to complex motor-driven vehicles, it was yet necessary to enhance the design of vehicles to increase the experience of drivers and passengers with machinery. Many technologies have been used to improve the interaction between drivers and interior car compartments, to reduce fatigue and enhance comfort, including the development of several sorts of electronics and electro-mechanical devices, sensors, software, and innovative new materials [2-4]. The science of "ergonomics" helps in the design of products and systems for the interaction between machines and the people who use them. Along with many measures to reduce road traffic deaths and injuries, protecting car occupants, "ergonomics" contributes to upgrading the human-machine relationship.

Notwithstanding this scientific and technical effort, 1.35 million people die on the roads worldwide every year, and as many as 50 other millions are injured [5]. It is worth mentioned that 23% of these deaths are pedestrians, 3% bicyclists, and 28% two- and three-wheelers; thus, more than a half of those killed and wounded in traffic crashes around the world are the so-called "VRUs" (Vulnerable Road Users): pedestrians, cyclists, mopeds, motorcyclists and passengers in public transport [5]. According to [6], the risk of dying for pedestrians and cyclists due to street incidents is about 8 or 9 times higher than that of the occupants of motor vehicles. Moreover, the most significant part of these accidents is due to the collision of the VRUs on the front parts of motor vehicles: hood, grill, lights, and bumper. Beyond the suffering, a road crash traffic can take survivors into poverty, and their families to face the long-term consequences, including the medical, rehabilitation, and funeral costs, and in many cases, the loss of the family's financial supporter. Therefore, in safety and economic terms, there is no difference between a driver, a passenger, a pedestrian, and another human sharing the way with vehicles, beyond their specific role in the road, in a particular moment.

Initially, road constructors focused their attention on the needs of motor vehicles, and VRUs were neglected. Roads were built wider and redesigned due to the increasing number of vehicles. Pedestrians and cyclists were invisible, except when authorities intentionally restricted their movements to ease the flow of motor vehicles. With these limitations, the risk for pedestrians and cyclists to become a victim of traffic increased dramatically [7]. At the end of the 1970s, a reversed trend began to appear in some European countries: reduction of traffic of self-propelled vehicles, redistribution of the streets, more and better public transport, improved facilities for pedestrians and cyclists, and the acknowledgment that the roads were not only for cars, but also for pedestrians.

One of the lines of action consisted in focusing on human behavior, as the primary cause of road traffic crashes and incidents [5]:

- Drinking increases the risk of involvement in a crash. The World Health Organization (WHO) recommends a limitation by law of no more than 0.05 g/dL of BAC (Blood Alcohol Concentration) for experimented drivers, and 0.02 g/dL for commercial, novice, and young drivers
- Maximum car speed in urban areas should not exceed 50 km/h in general, and not exceed 30 km/h in areas with high pedestrian activity. And should be even lower near places with people with reduced abilities, like hospitals and schools

- Use of devices such as helmets and seat-belt must be mandatory
- Application of restrictions for children (child seats for infants, booster seats for older children, and the banning of children in front seats)

In the 1980s, the idea of comprehensive road networks for pedestrians and cyclists was introduced. Some countries began to take measures prioritizing the needs of VRUs, and recognizing the importance to build protective environments when making political and planning decisions:

- Building specific pedestrian and/or bicycle-only routes
- Demarcating pedestrian and/or bicycle lanes, tunnels, and car-free play areas
- Reducing speed in certain areas where VRUs are most exposed to car hazards
- Excluding cars from the city center at specific times
- Developing high-capacity public transport systems.

Looking at the current deployment state, it can be seen that these measures have not been enough, and several factors could get this situation even worse. The migration of people from rural areas to cities and the aging of the world population put every year more VRUs with reduced abilities in the ways.

While industry invests massive amounts of resources improving safety and other characteristics of vehicles to make them more attractive to buyers, there has been a historical lack of investment in enhancing the security of VRUs. Therefore, it is imperative to build safer vehicles and roads, and improve the relationship between vehicles and every kind of VRUs, particularly in aspects around safeness. All these concerns encourage the development and application of innovative technologies. Therefore, it is the topic of this study: the safety of VRUs.

The rest of this paper has been structured as follows. Section 2 introduces concepts related to vehicular networks, while Section 3 justifies its usage. Section 4 delves into "pedestrian behavior". A study of Vehicle-to-Person networks technology is done in Section 5. Finally, Section 6 finalizes the paper with the conclusions.

2. VEHICULAR NETWORKS

Progressive vehicular technologies seek the convergence between the needs of drivers, transport authorities, and VRUs, bearing in mind the environmental issues of current society. This convergence looks for the development of new efficient and reliable transport paradigms, resulting in a new "smart" transport model known as the ITS (Intelligent Transport System). Among these new paradigms is the protection to VRUs areas, using inputs from several fields of research, e.g., smart and green cities, data communication techniques, and "Vehicular Networks".

A vehicular network consists of moving vehicles that act as mobile computing platforms, similar to laptops or cellphones but with very much faster speeds of displacement, within an optional infrastructure of mobile and fixed-location resources, and form together a source of data traffic of heterogeneous nature. The goal of the vehicular network is to connect vehicles spontaneously between themselves and the road resources, through short-range wireless network available devices, creating a combination that allows a car to interact with other cars and with local or remote services, such as traffic and emergency information, infotainment, and legal issues, among others [8].

Vehicular networks will be the communication basis of the ITS, delivering services of diverse characteristics to drivers and passengers, thus attracting considerable attention from the research community and the automotive industry [9]. Road safety, traffic information and optimization, self-driving, and parking assistance are the main issues that motivate the ITS, but this new technology will also offer a wide variety of benefits to car occupants, including web, music, and multimedia contents, network games, access and transfer of files, communication with their home network, access to business and job-related resources, communications with other drivers, and even with pedestrians.

The heterogeneous network scenario of the vehicular networks allows a varied architecture for the infrastructure in highway, rural, and urban environments; it can be built with wireless hot-spots along the road, integrated into the existing cellular systems, included in traffic signals, or deployed separately. Thus, the design, deployment, and operation of the infrastructure could be executed in several ways, by network operators, ISPs (Internet Service Providers), private integrators, and/or governmental authorities. Moreover, vehicles can communicate directly or indirectly with other vehicles without the need for the infrastructure, using WiFi or WAVE (Wireless Access in Vehicular Environment), for example. To this end, vehicles must cooperate and forward information on behalf of each other.

Vehicular networks are a trend today not only between scientists and engineers, but in societal leaders too, in their desires to give proper tools and directions to the evolution of the local national transport system. The current human society asks for communication technologies that facilitate connectivity to the transport actors, meaning not only users, but vehicles and infrastructures too.

Table I: Primary Use of Different Buses in Automotive Applications

	Feedback Control	Discrete Control	Diagnostic & Service	Infotainment & Telematics	Maximum Speed
CAN	Primary use	Primary use	Primary use		1 Mbps
LIN		Primary use			20 Mbps
MOST				Primary use	20 Mbps
FlexRay	Primary use				10 Mbps
TTP/C	Primary use				25 Mbps
TTCA	Primary use				1 Mbps

The ITS can collect and deliver data from different heterogeneous sources (e.g., smart cities, smart roads, and smart vehicles), with new "smart" communication technologies, e.g., V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-

Infrastructure), and V2P (Vehicle-to-Person), just to mention some of them. Finally, all of them will converge in a broader heterogeneous platform denominated V2X (Vehicle-to-Everything), with the requirements of developing devices, services and applications that will facilitate and enhance safety and social interactions [10]. The V2X connection will mean a totally connected vehicle, able to communicate with every object around, near and far from itself: traffic lights, other vehicles, toll gates, parking meters, VRUs, and pets on the road. Moreover, office resources and home information will be remotely reachable from an ordinary car.

The communication system of a car can be divided into in-vehicle and out-vehicle communications. The in-vehicle communication takes place between elements of the same car. According to the intended use of communications technologies, the future V2X market can include:

2.1 IN-V (In-Vehicle Communications)

The car itself is equipped with numerous sensors managed by local controllers that are now connected together with standards buses, replacing the legacy proprietary connections that were used formerly. These systems are running on communication architectures with different types of buses such as CAN, LIN, FlexRay, etc (see Table I), enhancing the perception of the driver and providing differ-ent functionalities from advanced control to entertainment [11].

Some feedback and control functions can include a wide variety of operations from switch-on and switch-off devices or lights, automatic action of wipers, diagnostic from the engine and drivetrain sensors, and commands over the mechanics and electronics of the vehicle, e.g. engine control, ABS (Anti-lock Braking System), ESP (Electronic Stability Program), and anti-roll system. Furthermore, comfort functions embrace cruise control, steer-by-wire, and infotainment applications (e.g., Internet connection, music, and video).

Finally, the IN-V network must provide functionalities during the life of the vehicle, including in diagnostics and service stages, and access to telematics of the vehicle, that is, the set of functions that uses networks outside the vehicle to perform tasks like communications and environment sensing [12].

2.2 V2V (Vehicle-to-Vehicle)

In V2V, messages are transmitted from one vehicle to another one. They can carry information from near and far sources. Near source data usually come from the environment, and are related to alerts and warnings in the pathway. It is absolutely vital that this kind of data travels as-soon-as-possible since nearby moving objects can be in danger, or can be a source of danger to other objects, due to road accidents, road obstructions, and approaching emergency vehicles. On the other hand, far source data are frequently related to the Internet. Their delivery is not normal-ly an urgency issue, since they mostly deliver e-mails, web browsing, data storage, and multimedia applications [13]. Direct V2V communications have the advantage of no need for an external support (i.e., an infrastructure), but has a distance limited to the propagation range of the signal; hence, the ITS answer is based on hops, in a cooperative form. This collaborative routing has to deal with network delay and latency to make them acceptable for alert messages delivering, under unpredictable size, form and density of the dynamic topology, and fast-changing weather conditions.

Handling communications and safety in vehicles that share a via and infrastructure, at high speed, and under uncertainty of routing, weather, etc. is not trivial. Hence, this area of development must be grounded over reliable and robust wireless communication mechanisms that also minimize the administrative overhead. This has led some countries around the world to invest in research programs. In Europe, the main programs are the EU "Intelligent Car Initiative" and "CAR 2 CAR Communication Consortium", where the latter is driven by the industry [15][16]. In the USA, the Intelligent Transportation Systems Joint Program, a program of the US Department of Transportation opens to private collaborations, formerly known as VII (Vehicle-Infrastructure Integration) [17][18]. In Japan, the ASV (Advanced Safety Vehicle) [19] program is already in its sixth phase. Germany [20] is also well positioned with the integrated statecraft for the development of the new driving technologies.

These initiatives have generated technologies that are currently in use, like ACC (Adaptive Cruise Control), Lane Keeping Support (LKS) system, ABS (Anti-lock Braking System), Curve Overshooting Prevention support system, Night Time Forward Pedestrian Advisory System, Stop-and-Go system, AEB (Autonomous Emergency Braking) system, and Emergency Braking Advisory system [21][22].

2.3 V2I (Vehicle-to-Infrastructure)

Under this scheme, vehicles and roadway elements (called infrastructure, in general) exchange several sorts of data, including critical safety and operational data. The primary goal of this exchange is to avoid motor vehicle crashes, but it should not be limited to this area. In 1984, a communication protocol named RDS (Radio Data System) enclosed small amounts of data in FM radio broadcasts, becoming the first I2V (Infrastructure-to-Vehicle) communication system [14]. The nomenclature I2V and not V2I corresponds to the fact that this system was unidirectional from the infrastructure to vehicles, and there were no communications from vehicles to the infrastructure. In 2005, a new version of RDS included TMC (Traffic Message Channel) was released, and consisted of messages with events and location codes, expected incident duration, affected extent, and other details.

In V2I, each vehicle should be equipped with an OBU (On-Board Unit), which collects the IN-V sensors data, transmits them through a transponder, and interprets the incoming messages from its environment (infrastructure, pedestrian, other vehicles, etc.).

2.4 V2P (Vehicle-to-Person)

V2P also stands for Vehicle-to-Pedestrian or for Vehicle-to-Pets, and facilitates the integration of VRUs to roads and sidewalks, by offering communication to/from the vehicles, to/from the people, and to/from the pets, ensuring by this way the safety to VRUs.

On the one hand, vehicles must be equipped with the new standards. On the other hand, VRUs must carry some sort of wireless communication devices (e.g., smartphones or collars with a transmitter). In the near future, it is desirable that small devices, like smartphones, incorporate DSRC [98] (Designated Short Range Communications) technology. With DSRC, GPS and local sensors, it will be possible to find out the exact location of VRUs. Current smartphones have WiFi technology, enabling anyone with a smartphone to receive and send this kind of messages from/to vehicles around, with the proper software. Some carmakers have this approach[1], but traditional WiFi was not designed for high-speed mobility; hence it is not efficient for vehicular networks. Other carmakers prefer DSRC/WAVE and fusion the data from sensors and GPS to determine the exact location of partakers; in the pedestrian side, software will show warning and alerts on the device (e.g., the smartphone) while the infotainment system screen will do something similar on the vehicle side[2]. Additional measurements, such as AEB (Autonomous Emergency Braking), can be taken to reduce the chances of a collision.

2.5 *Other Technologies*

Ceaseless advanced research is currently working over other technologies of recent creation:

- V2M (Vehicle-to-Motorcycle) and B2V (Bicycle-to-Vehicle) share a similar approach to V2P, because both are aimed to VRUs safety and share similar tools.
- V2A (Vehicle-to-Application) embraces a limitless variety of applications that can support people in an automobile, monitoring the driving behavior for the safety of the vehicle and passengers, reporting relevant messages, sharing information and control, in and out the vehicle, etc [23][24].
- V2H (Vehicle-to-Home) and its related schemes V2B (Vehicle-to-Building), and V2C (Vehicle-to-Community) deal with techniques to deploy, manage and access electrical power systems for electric vehicles, in interest to reduce oil consumption and contaminant emissions [25-27].
- V2G (Vehicle-to-Grid) and its related V2L (Vehicle-to-Location) embrace the bindings between home power-producer systems like electric cars, solar panels, windmills, etc. to a company's power grid. It departs from the idea that a small power producer could be self-sufficient and autonomous from the grid, and even could become an electricity provider generating revenues through smart charging and trading of electricity. In practice, this scenario is currently only adopted by a small group of technology enthusiasts, among other reasons, because usually there is a wide variation between the amounts that companies charge, with respect to what they pay to the small producers. Currently, electrical cars manufacturers support this innovative technology for vehicle charging, through charging station networks, like Tesla [26][28-30].

3. MOTIVATION OF V2V AND V2I COMMUNICATIONS

As can be seen, safe navigation has been the first motivation behind V2V and V2I communications. Posterior applications embrace many fields [31-54]:

- Traffic Signals: Time of signaling can be augmented or shortened according to vehicular and pedestrian traffic.
- Managed Lanes: The technology enables the management of configurable lanes. Therefore, HOV (High-Occupancy Vehicle) lanes, toll lanes, reversible lanes, and emergency lanes can be reversed, opened, closed, changed, and cleared, in realtime.
- Transit Stops: Mobile devices can interact with stops of public transport services, like buses. If no passengers are waiting, the bus driver can avoid unnecessary stops, or simply omit the station.
- Electronic Toll: Electronic toll collection and electronic payment applications reduce costs and time for both sides, the driver and the transit authority.
- Anti-Bunching: Bunching means that several vehicles of the same kind/route get lumped along the way. Intercommunication ensures to travel evenly spaced.
- Dynamic Rerouting: A vehicle can know about congestion many kilometers away, and take the adequate action such as an alternative route.
- Early detection of accidents: Operators of Emergency Services can detect the exact places of incidents quickly after the occurrence from a long distance, and act without delay.
- Location of stolen/suspicious cars: The infrastructure network acquires data when a car passes by the Road-Side Units (RSU), and sends this data to be processed at a higher level. According to the result, an alert can be sent to the respective authorities.
- Accident Reconstruction: Investigators of insurance companies or police can inspect post-accident information registered from sensors and stored in by the on-board computer to check road conditions, neighbor cars, and other factors for forensic reconstruction of road accidents. Moreover, the information stored will also help to judge the driving behavior of the driver at the moment of the accident.
- Pollution Control: Transportation is one of the main sources of greenhouse gas emissions. A percentage of these emissions are due to unstable speed profiles and excessive acceleration. ITS technology can be effective in improving driving conduct, in terms of smooth speeds and acceleration rates by providing real-time traffic information.
- Parking Assistance: Reduction of wasted time when cars are cycling for a parking slot means a reduction of fuel consumption too. The parking-assistance devices send signals pointing out the available places.

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[1] http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2012/Jul/0726_pedestrian.html

[2] http://quartsoft.com/blog/201309/honda-v2v-v2p-technology-smartphones

- Office-on-wheels: Conventional office applications like writing reports, downloading files, and reading e-mail are combined with movies and multimedia in a new environment: the car. This will allow the passengers of a vehicle to work even when they are stuck in a traffic jam or just enjoying a highway ride.
- Infotainment: Mobile Internet games, mobile shopping, and location of local services will make cars with wireless communications not only more integrated with the world, but also will become an aim for advertisements.
- Telemetry: Performance measurements, and in general, any sample from IN-V sensors can be directed to servers to record and/or analyze the performance of a subsystem in the cars or the behavior of an environmental factor. Insurance, mechanical services, and rental companies can evaluate these measures in their central servers, and take the corresponding actions. National weather services will take advantage of external thermometers and humidity sensors to forecast the weather.

Currently, these systems are being simulated on computers, and tested on roads designed and built for this purpose. The outcome of this research will determine how technology can prevent accidents in the ways, enhance the traveling experience, keeping in mind that transportation services include the movement of people, live creatures, and goods. Information that is gathered in tests will help to choose which safety features will be compulsories in every future vehicles [55-58].

4. PEDESTRIAN BEHAVIOR

Human beings are naturally endowed for walking. Thus, in ancient times, walking was their unique transport means. Later came tame animals, mechanical devices, and electro-mechanical devices, so currently walking is relegated mainly to indoors, and to relatively short distance displacements; in spite of its restricted use, worldwide, every year about 400,000 pedestrians lost their lives in clashes associated to automobiles. The danger increases with age: nearly half of these pedestrian fatalities in Europe imply elderly pedestrians. Avert this kind of crashes has therefore become the focal point in plenty of investigation, generating new branches of study among the Computer Science field [59][60].

It is usually thought that walkers are to be blamed of these incidents, because they supposedly have a lower priority in the use of streets [61]. And it happens since chariot's time, before the invention of motorcars, as a lawyer, Mr. Justice Mellor, stated in 1869:

> *"Accidents happen because the drivers do not believe, or at any rate, will not admit, that foot-passengers have as much right to cross a street or thoroughfare as persons driving have to pass along it."*

Then came studies about pedestrian behavior. Their primary goals were to obtain data to design traffic regulations and, accordingly, pedestrian safety protections. Lately with the advent of computers, computer simulations arrived along-side the pedestrian models. A computer simulation is an algorithm based in a mathematical model, that using a numeric method replicates the acts and facts of a studied system, ranging from basic science through social and economics. In countless situations, its contribution is irreplaceable, because in many areas, such as astrophysics, engineering, physiology, and climatology, there are phenomenons that are impossible to reproduce, or at least, not possible to reproduce without harming some systems [62-64].

Currently, the pedestrian computer simulations are considered an imperative prime appliance to study living subjects conducts and design proper pedestrian facilities, in spite of the opinion of social psychologists that consider mathematical modeling a "reductionist" approach, especially because of its lack of social patterns. The field of action of these psychologists can be seen as an open system where elements change their behavior upon changes of circumstances around them; thus, the modelers must develop techniques that include multiple and circumstance-variable conditions, and separate the components of the problem, to adequately represent these scenarios and the dynamic rules of the elements (see Figure 1). Subsequently, road proponents could bring on better-designed pedestrian facilities [65][66].

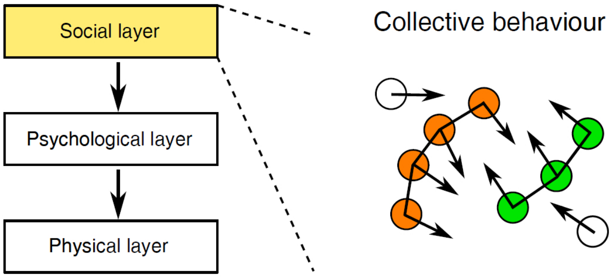

Figure 1: Separation of the Model in Three Layers. The Social Behavior (Yellow) is Studied Apart

4.1 Characteristics

To drive these studies, characteristics of pedestrian behavior must be considered [67-75]:

- Stop and parking: Walking is not constrained by road infrastructures; even more, living beings can stop at any time, and at places where they are not supposed to stop. Moreover, living beings do not need to park.
- Route: Routes of pedestrians are altered irregularly because they have to react to rising obstructions, the environment, and a cellphone interaction. Furthermore, they can cross the street where it is not supposed to be allowed.
- Predictability: Pedestrians do most of their socioeconomic transactions on foot at any place, making their conduct pretty less foreseeable than drivers' ones. In the case of animals, their behavior can even respond to physiological needs, at any place.
- Size: Vehicles need a very well-defined space to drive and to park. In contrast, pedestrians require a minimal, and in certain conditions compressible, space to behave. In some

studies, this property is compared with complex fluids or rarefied gases.

- Speed: Pace of pedestrians derives from several factors that include: (1) extension of city and/or distance to travel, (2) environment (weather, lighting, and way conditions), and (3) own conditions (purpose of the trip, age, and physical conditions).
- Gap Acceptance: Is a subjective criterion of how safe it is to cross the street using the gap between the last and the coming car. This subjective calculus reduces the options to seconds, or even fractions of seconds in the extreme scenarios.

4.2 Studies

Modern conveyances and sedentary life affect human health, so walking is a prophylactic measure. Also, as stated previously, pedestrian activities bring them to share the roads with vehicles, thus these activities have to be studied to warranty their safety.

Empiric observation is the most used method to gather behavioral data that are mathematically studied. In terms of probabilities of pedestrians walking in response to stimulus or mandatory acts, like crossing in the marked crosswalks, or crossing at the indicated time, values are measured in function of delay and/or time-of-arrival [76].

Modeling methods can be roughly divided into two kinds: macroscopic and microscopic models. These two models have very differentiated features. Macroscopic methods study living mass along the time, considering groups of pedestrians as a whole, and consequently ignoring interactions between individuals [77][78]. These models have better computational performance because they assume that this “mass” or population is comprised of homogeneous agents; but are far from representing adequately real-world situations. On the other hand, in microscopic models, the focus relies on the behavior of individual elements representing living beings, as well as the effect of every element on others around themselves. While microscopic models can represent precise pedestrian behaviors in a wider number of situations, this level of detail needs more computational resources, and thus slows down the computational processing speed [79][80].

Due to their high degree of details, microscopic models have become the best suited to represent the behavioral rules that each entity applies, and to identify the interactions among them too. V2P (Vehicle-to-Person) studies focused on the networking part rely mainly on this kind of models [81].

4.3 Tools

For humans, detect and correctly decode the shape and behavior of a living being is intuitive and can be considered as easy. However, in the field of computers, it has been hard to represent the conduct of people due to the lack of good models and the required computational power. The available computational resources restraints the capacity of correctly allocate a group of living beings sharing the environment with vehicles and inert objects, at least in an enough small portion of time. There are too many parameters, not only silhouette, surface, color, pose, lighting, and separation from the background that computers must calculate, but also factors such as speed, acceleration, direction, uncertainty, etc. Furthermore, this environment is ever changing and a bounded simulation time is vital; machines should correctly position VRUs at least in real-time, so drivers and on-board computers can avoid crashing against them with enough time ahead [60][76].

The variety of resources that have been used to provide a measurement for active pedestrian acts is very wide and includes LOS (Line of Sight) types, N-LOS (Non-Line of Sight) types, and several other techniques mainly derived from video sources [82-86]:

- LOS: such as laser, radar, and GPS. GPS is particularly useful in rural and suburban environments, where other technologies cannot reach, but is less recommended in highly dense areas, due to its lack of precision.
- N-LOS: such as 3G telephony, WLAN, and RFID (Radio Frequency IDentification). The RFID-based methods have severe limitations, in range and in the disposition of pedestrians to carry an additional device. 3G must rely on the surrounding resources, while WAVE (a WLAN) can work in an autonomous way.
- Other solutions include video detection and analysis that are already present in many high-end cars, and in the use of the front and rear cameras of a smartphone, in the case of pedestrians. Both share the aim to alert and avoid a crash, but there is a big difference between them because in a car this technique represents just another source of electric and computational drain, but in a pedestrian, these drains can result in the discharge of the battery and the occupation of the scarce computational resources (processor and memory) that could make this approach impractical.

The objective of this variety of technologies is to operate concurrently for an “ideal” solution that:

- works outside and inside particular portions of ways like bridges, tunnels, etc.
- positions the objects accurately.
- gives information in real time, or even better, make prediction.
- is ubiquitous, that is, every vehicle and VRU must have the solution; and ideally, the infrastructure (road) also has it.
- works in any weather condition (e.g., fog, rain) and any lighting condition (sunny, cloudy, night).

These solutions must be concurrent because currently there is not a technology that solely has all the advantages, without any limitation. Taking the GPS for example, it is universal. It works in any place around the world, and most smartphone already has it. But its strong dependency of Line of Sight (LOS) to the satellites continues being a major problem. Also, GPS suffers the problems of its high dependency on processing and lack of precision. Hence, if the satellite system is used for positioning, it needs help from other technologies, such as sensors, Bluetooth, WiFi, and video; all together with the proper software that coordinates and calculates positioning approximation.

An enhanced scenario includes the fusion of information from two devices of different philosophy of work [87-89]:

- A positioning system using signal strength, i.e. RSS (Received Signal Strength), supplemented with some kind of motion embedded sensor, i.e. INS (Inertial Navigation System) to position a smartphone/vehicle.
- An embedded sensor, complemented with an embedded camera to surely position other users, devices, or vehicles. This is the approach used by Tesla Motors in its software.

Nevertheless, accurate ubication has been achieved in two dimensions. Including a third dimension would be very useful to determine positioning in bridges, tunnels, and buildings. In the future, the use of sensor networks, NFC (Near-Field Communication), and Bluetooth installed in the environment will ease positioning [90].

4.4 Outcomes

Any study about humans is a complex problem; to adequately represent elements in the system, examinations must include classifications according to sex, age, economic status, geographic location, and every other relevant detail. Then comes statistical processing. If to that complexity, we add the unpredictable nature of humans when making decisions, modeling of pedestrian behavior tends to be a pretty tangled one. Thus, scientists need to know every detail about mechanisms used by pedestrians when they decide their next movement in an range of conditions and situations, e.g. from young and elderly pedestrians, corner and mid-block crossing, and marked or unmarked crossing, because traffic accidents concerning pedestrians are a public health problem, when interacting with motor vehicles [91][92].

Technologies that can help to collect information about pedestrian behavior have not been deployed sufficiently, whence generating a deficiency of data; whereby many researchers center their indicators on macroscopic-modeled results. With the advent of better (and better deployed) technologies that augment granularity and accuracy of data, the outcomes of studies will reveal very useful knowledge that will help to avoid accidents, diminish the number of injured persons, and save lives. Present outcomes from actual studies exemplify details of several aspects of this subject area [93][94]:

Environment:

(a) Roadway characteristics such as average daily traffic volumes, speed limit, number of lanes, and land use patterns around the crossing have been shown to have an impact on pedestrian crash rates.

(b) Longer crossing distances and crossings with more lanes can be more dangerous than narrower crossings.

(c) Sidewalks tend to decrease crash rates.

(d) Urban areas have higher crash rates than rural areas, but the number of non-residential driveways within 50 feet of an intersection is positively associated with pedestrian crashes.

(e) Neighborhoods with low and median annual income, and proximity to alcohol sales establishments are associated with elevated crash rates.

(f) Higher crash rates occur around malls, schools, and parks.

(g) The number of commercial retail properties within 0.1 miles of the intersection is positively associated with pedestrian crashes.

(h) The percentage of residents living within 0.25 miles of the intersection that are younger than 18 is positively associated with pedestrian crashes.

Signaling:

(a) Crash rates increase with the speed limits at uncontrolled crossings.

(b) Right-turn only lanes are positively associated with high crash rates.

(c) Median islands and Danish offsets (a pedestrian island in the shape of a "Z" which causes the pedestrian to look in the direction of oncoming traffic before crossing) have been shown to mitigate pedestrian crash rates.

Yielding:

(a) Drivers are less likely to yield to pedestrians when approaching non-signalized crossings at higher speeds.

(b) Pedestrian actions are less predictable than those of motorists. Without an adequate infrastructure that protects pedestrians when they pivot, rotate, or change their course, large high-speed roads make it difficult for cars to yield to them, becoming a significant source of pedestrian fatalities.

(c) Another study at six crossings of varying lane width and speed limits between 25 and 30 mph found that marked crosswalks improved driver yielding rates.

5. VEHICLE-TO-PERSON NETWORKS

For a pedestrian, sharing the roads with vehicles is a dangerous experience. In rural, suburban, and even in many cases in urban environments, people must abandon the footpath or sidewalk to move on foot directly on the roadway, exposing themselves to be run over by a car. Even further, walking, standing, or sitting in the sidewalk does not warranty safety for pedestrians: at any moment, a vehicle can invade the footpath and cause severe injuries or the death of that person. This situation has been aggravated with the appearance of mobile devices like smartphones, tablets, and handy video games, which are distracting elements that decrease the time of reaction of pedestrians against dangers [82].

Since the very beginning of the automotive industry, authorities have tried to organize traffic. The first traffic light appeared in London, England, in 1869, giving the pedestrians 30 seconds to cross the street every 5 minutes. But from that very beginning, problems started too. Neither pedestrians nor carriage drivers always obey the signal. Thence, from those old times, authorities studied alternative resources. In the mentioned case, the final decision was to dig several pedestrian tunnels to help safely crossing streets. Not many posterior efforts for pedestrian security were made, because automotive traffic had and has a supposed superior level of importance than pedestrian one, as was mentioned previously. Because the psychology and behavior of drivers had not been studied enough, regulatory efforts frequently aimed to not-so-clear targets, as this statement in the upper chamber of England in 1938 illustrates [61]:

> *"We (pedestrian) do feel that if subways and bridges were put into general operation, it would only confirm the view of the motorist that the public highway was a motor speed track and would lead to further accidents"*

As time passes, and human society has been supported more and more by automotive vehicles to develop its activities, the first concern to appear were the killed and injured passengers inside vehicles, whereby the first safety measures were taken to protect them. But as more and more accidents involved VRUs, it became evident that they need protection too. This protection started in the car itself. Its structure began to be designed or covered with bonnets and bumpers to passively diminish the impact of a hit, when a pedestrian faces a crash [95-97].

In a vehicular network, vehicles are equipped with wireless interfaces that can include Bluetooth, IEEE 802.11a/b/g/n/ac (WiFi), IEEE 802.11p (WAVE), and LTE (Long Term Evolution), among others.

For V2V communications, many transmission technologies are available and include the use of infrared beams, VHF waves, microwaves, or DSRC [98] (Dedicated Short Range Communication), among others. DSRC was defined by the US FCC (Federal Communications Commission) as a specific communication standard for ITS use, designed to meet the extremely short latency requirement for road safety messaging and control [98]. It works on the WAVE (Wireless Access in Vehicular Environments) 5.9 GHz band standard, can reach near 1 km range in the best case, allowing communications between vehicles with speeds not superior to 160 km/h, and has a relatively low latency of 50 ms. DSCR is designed in a simple way: OBUs (On-Board Unit) and RSUs (Road-Side Unit). The RSU emits announces to OBUs and other RSUs, approximately ten times per second. Receivers listen warning and safety messages on the control channel, authenticate sender digital signature and execute applications giving priority to safety ones. IEEE 802.11p, an approved amendment to the IEEE 802.11a standard to use a WiFi alike technology in vehicles, takes charge of PHY and MAC WAVE layers. IEEE 1609.2, IEEE 1609.3, and IEEE 1609.4 work in superior layers of WAVE [99]. It will probably be one of the main supports of the ITS, so the near future's tendency is to make wireless technology more accessible, ubiquitous and inexpensive, which in turn will foment the appearance of numerous innovative vehicular applications. Moreover, future compulsory requirements for installing DSRC modules by US NHTSA (National Highway Traffic Safety Administration) in new vehicles in the USA market will accelerate even more this tendency[3].

Statistically speaking, the majority of accidents are due to human mistakes made inside and outside the vehicles. In this order of ideas, many incidents would be avoided, or their consequences minimized if vehicles were equipped with adequate technologies that could [60][100-102]:

- detect a person (or other moving subject) in order to activate safety systems to avert an accident. Depending on the situation, these safety systems could totally avoid the crash. In other cases, they would try to avoid the collision but will only reduce the impact.
- analyze the situation fast enough to alert the driver and simultaneously take necessary actions to prevent the crash. In this scenario, fast means real-time, or even quicker, by predicting dangerous scenes.
- release the driver of the responsibility of driving. Or limit his/her duty with some mechanisms that restrict his/her responsibilities, cutting off this power of driving, and others controls, and transfers this power to some algorithm that takes the control, to avoid the crash.

The control means to have "eyes and ears" to detect the pedestrian and his/her environment. Beyond the theory of the largely studied methods to determine distances and positioning, like trilateration, triangulation, ToA (Time of Arrival), AoA (Angle of Arrival), and RSSI (Received Signal Strength Indicator), among others, the eyes and the ears of any vehicle means information sourced [104-106]:

- locally from sensors: such as IR (Infrared), laser, and radars embedded in the vehicles' structure. The restriction of sensors is the distance, worsened by varied obstacles in the form of climate, curves, trees, walls, electromagnetic noise, and so on.

  Especial mention is reserved for digital video cameras, a form of sensors whose outcome need to be adequately studied by the on-board computer powerful enough to do the additional job of analyzing and interpreting the video frames, and to give valuable information so quickly that it can be useful; a delay in any of its stages would make this information useless.
- externally from the network: from the infrastructure of the roads, and from other vehicles. The ITS propounds DSRC, the technological platform that uses WAVE. But, because of the scarcity of bandwidth in the 5.9 GHz band presently assigned to WAVE, and the very limited number of devices currently using WAVE, communicating alternatives, like WAVE using LTE 5G, are necessary.
- externally from people/pets: on the pedestrian side, it should exist at least an equivalent mechanism to alert the proximity of a vehicle. Direct and full-duplex connection from cars to pedestrians, using the proposed and already-used technologies including Bluetooth, RFID, ZigBee, and even WiFi, should imply many advantages as fast notification and accuracy. As it means that pedestrians should carry battery-powered equipment for their safety, it is logical to suppose that the same reasoning is applicable to pets and other animals. Currently, naturalists apply sensors to wild animals to study migrations, habits, and population size. Hence, the acronym V2P for Vehicle-to-

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[3] https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication

Person can be extended to Vehicle-to-Pet. If the carried-on device is IEEE 802.11p compatible, it would be a major integration in the vehicular network world, given the already present GSM/LTE technology in many modern vehicles.

In general, an ideal V2X must position every actor: living or inanimate, mobile or fixed, rolling or walking. The indirect approach consists of: pedestrian first connects to the infrastructure, and the vehicle gets the position of pedestrian from it. A direct approach is desirable. To this end, it is necessary to integrate WAVE to the devices carried by pedestrians (e.g., smartphones). A complete integration of pedestrians into the ITS would offer numerous benefits and applications to every actor of the roads. It is very likely that the penetration rate of the WAVE technology on the pedestrian side is going to be faster than in the vehicle side, as the lifetime of mobile devices is shorter than cars' one. Averagely, a mobile phone lasts 18 months, but the lifetime of a car is for several years. In this way, a distracting and entertaining phone can become a solution, by notifying its owner of unsafe situations. As proposed in [82][102][107], the integration of IEEE 802.11p on the VRU side should be compulsory.

Rules of design in urban and extra-urban environments must evolve to fit all their population [63][64]:

- Humans: Where both extremes of ages, children and elderly, are the most vulnerable. Intelligent Pedestrian Traffic Signals (IPTS), dedicated transportation, and surveillance for personal safety are a good complement, but are not enough. A more radical approach is to diminish superficial traffic as much as possible, to get a more walkable city[4].
- Animals: A simple IEEE 802.11p compatible collar for pets would be a nice start, but it would only apply for animals that have an owner. Thus, a public service would be necessary to equip big wild animals with probability of crossing a road, if we want to avoid crashes between animals and vehicles.

6. CONCLUSIONS

Due to the number of fatalities in road accidents, traffic authorities are committed to reduce road crashes. The technologies that can improve public safeties will follow the same path of the seat belt: they will become compulsory. A big effort is required to integrate VRUs into the system, and to improve their safety since they represent the largest portion of the number of wounded and deaths. Up to recently, laws and research tended to strengthen the security of cars, resulting in the development of technology to make cars safer; However, the security of VRUs has become a priority worldwide, and this tendency is irreversible. Following the aforementioned tendency, it is expected that a lot of proposals and laws will appear in the near future to protect VRUs. V2P developments will bring new actors to the vehicular network market: clothes, watches, cellphones, glasses, personal accessories, pet accessories, and many more.

WAVE is a standard of the IEEE that brings communication to the ITS. It was initially targeted to the physical safety of the drivers and passengers, but the community has already proposed a plethora of applications. Access to services as infotainment, web, and cloud inside the car will explode and require more bandwidth. Whereby, IEEE 802.11p will need an amendment, a major upgrade, or a replacement.

Technologies used to improve the interaction between drivers and cars will become a commodity. Nowadays these appliances draw public attention, but car manufacturers will have to improve these technologies continually, to reach the consumer preferences.

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