Technology scenario for Connected and Automated Vehicles infrastructure planning

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Partner: Area Science Park

Authors: Barbara Monaco, Marco Slavich, Michela Zornada

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Abstract

What are the potential effects of self-driving cars on urban development?

How is the autonomous road vehicle idea incorporated into the policy goals for long-term urban development?

What are the difficulties associated with a lack of data on the effects of autonomous vehicles on urban development?

What are the advantages of using self-driving cars as a mode of transportation?

This scenario analysis is intended to be a support document for mobility planning authorities in the process of urban road transport electrification, highlighting relevant issues and topics together with trends perspectives.

The establishment of autonomous vehicles (AVs) and their integration with ridesharing services would force cities to confront a slew of unknowns ranging from safety, ethics, insurance, and regulatory requirements to technical needs, pricing, and the scale of widespread use. As people abandon car ownership in favor of ridesharing and, in the near future, ridesharing run by autonomous vehicles, cities will be forced to make difficult decisions about infrastructure, urban mobility, land use, social equity, and inclusion.

Abbreviations

ADAS: Advanced Driver-Assistance Systems

AI: Artificial Intelligence

APS: Assisted Park System

AV(s): Autonomous Vehicle(s)

BRT: Bus Rapid Transit

CA(E)V: Connected Autonomous (Electric) Vehicle

CV: Computer Vision

DSRC: Dedicated Short-Range Communications

HMI: Human-Machine Interface

ITS: Intelligent Transport System

MaaS: Mobility as a Service

PT: Public Transport

TNC: Transportation Network Company

V2I: Vehicle-to-Infrastructure (communication)

V2N: Vehicle-to-Network (communication)

V2V: Vehicle-to-Vehicle (communication)

1 Introduction

As a rising number of people switch to sharing mobility services and abandon conventional public transportation, policymakers must assess how an increasing share of AVs helps or hurts policy objectives. With no driver and no labour costs, a shared vehicle may deliver extremely low fares, easy service, and be highly disruptive in many cities. Cities that plan for this technology will collect numerous benefits, including the potential elimination of millions of cars from the road (if combined with shared mobility business models), a more sustainable climate, improved mobility, more safe roads, productivity and social equity, new job opportunities for drivers[1], and new design of existing parking spaces.

As with previous technological developments involving the railroad, streetcar, and automobile, public policy will play a critical role in shaping AV technology and directing its effects on the cities. Cities do not have much time to assess and shape how autonomous vehicles are used, and they must move quickly to define policies that mitigate the risks while maximizing the benefits. Because of the major impacts AVs can have on our cities, planners must consider them. There are possible positive as well as negative consequences, but none of them are certain. The secondary consequences are much more unclear. Planners, in collaboration with other practitioners, play a critical role in assisting societies in maximizing the benefits of technology while minimizing the detrimental effects.

Uncertainty must be factored into the planning process. While there is widespread consensus that autonomous vehicles are the next big thing in transportation, there is still a lot of confusion about how the technology will be applied. The time it will take for the technology to be fully deployed, the combination of traditional, partially automated, and fully automated vehicles over time, private ownership vs. shared use, and how AVs will impact metropolitan, suburban, and rural geographies are just a few examples.

Scenario planning can be used by planners to define the range of potential futures and policy responses that support the community's vision and goals. These topics concern community visioning and goal-setting, plan development, regulations, guidelines, and incentives, site design and development, public investments. Some of these points are about planning, while others are about putting the plan into action. All of them give the societies the chance to plan for AVs.

Unlike comprehensive plans, which address a broad variety of city-wide issues (i.e., land use, transportation, natural resources, and built environment design), functional plans focus on a single community structure, such as transportation, parks and open space, or economic growth.

Working and useful proposals should be aligned with the comprehensive plan's priorities and policies in their subject areas and provide more specific instructions about how to execute them. The transportation plan is the central functional plan for addressing AVs as an integral part of a municipality's transportation system. Transportation proposals used to include regulations for various

[1] https://www.cnbc.com/2018/08/10/autonomous-vehicles-are-creating-jobs-heres-where.html; https://technologymagazine.com/ai/will-autonomous-cars-eliminate-driving-jobs

modes of transportation, street/highway classification schemes and service levels, as well as transportation improvement programs and initiatives.

The World Economic Forum identifies three technological megatrends of the fourth industrial revolution (Industry 4.0), i.e., connectivity, artificial intelligence, flexible automation. The technology of the fully autonomous vehicle (AV) is aligned with these megatrends, especially in the case of connected and autonomous vehicles (CAV), which allow for the communication between vehicles, infrastructure and other road users (V2X connectivity). National and local governments will have to assess their transport strategy in view of the AV evolution. Furthermore, planning will have to adapt to this uncertain future. Taking into account that the purpose of the transport system is to provide access for people and goods to the locations where activity is conducted, it is evident that spatial planning and the organisation of land uses face their own challenges due to the implementation of AVs.

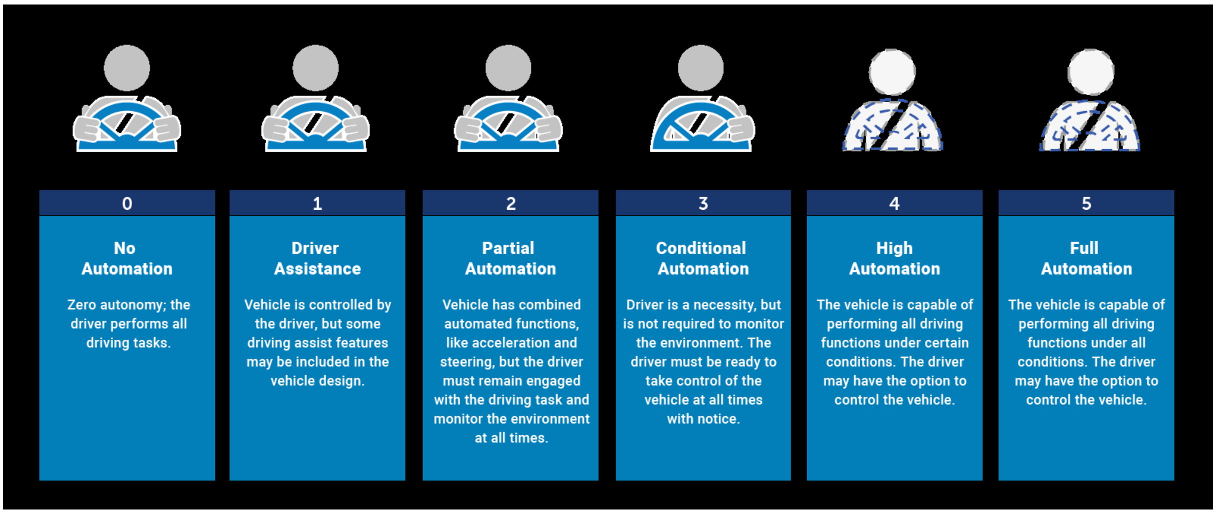
However, it is critical to resolve these issues as soon as possible, as analysts predict that fully autonomous road vehicles will be eligible for consumer adoption in the next decade and will make up a significant portion of the automotive fleet by 2050. Today, urban planners debate whether autonomous vehicles will help them achieve their goals, but cities of the future will almost certainly have to find ways to adjust to the advent of autonomous mobility, or mobility that is focused on autonomous vehicles. Understanding and addressing the challenges of urban planning is especially important in Europe, where urban areas account for 70% of the population (and are expected to rise to 80% by 2050), 80% of energy consumption, and 85% of GDP (Gross Domestic Production).

Under these challenging circumstances, urban planners must pool data from various sources, share information, and develop strategic synergies in order to assess the potential impacts of autonomous vehicles on urban areas and integrate autonomous mobility solutions into urban planning in order to meet the specific needs of the city in question while also achieving common socioeconomic and environmental goals.

2 Autonomous driving and smart roads

2.1 Smart vehicles

The Society of Automotive Engineers (SAE) defines six different stages of automation (L0- L5), ranging from fully manual to fully automated systems. This scheme is focused on the division of responsibility between humans and computers, starting with all human responsibility at L0 and ending with all machine responsibility at L5. Although commonly used and reasonable when discussing different approaches to automation, some argue that the six levels should not be viewed as a sequential deployment route. There may not be an appropriate business case for deployment at certain stages.



standard SAE J3016 (Society of Automotive Engineering)

To make these automation degrees easier to understand, some of them are sometimes associated with names that describe them: for example, level 1 is called "hands on", level 2 "hands off", level 3 "eyes off", level 4 "mind off" and level 5 "steering wheel optional" because any human intervention is superfluous.

In order to achieve a certain level of autonomy, the car detects the surrounding environment through specific technologies, such as radar, lidar, GPS and sensors, which are different depending on the level of automation (see the table below).

Level of automation	***Functionalities***	***Sensors/Technologies***
Level 1	▪ ACC (Adaptive Cruise Control) ▪ LDWS (Line Departure Warning System)	▪ Ultrasonic sensors ▪ LRR sensor (long range radar) ▪ Camcorder
Level 2	▪ All the features of Level 1 + ▪ LKA (Line Keep Assist) ▪ PA (Parking Assist) ▪ AEB (Automatic Emergency Breaking)	▪ All the sensors of Level 1 + ▪ SRR (short range radar)
Level 3	▪ All the features of Level 1 + ▪ DM (Drive Monitoring) ▪ TJA (Traffic Jam Assist)	▪ All the sensors of Level 1 (in larger quantities) + ▪ LIDAR (Laser Imaging Detection and Ranging) sensor ▪ stereoscopic video camera ▪ long distance video camera ▪ "Dead Reckoning" technology ▪ infrared or thermal sensors
Level 4	The car is able to handle most situations without the driver's action	▪ Ability to carry out the "sensor fusion" or linking of data from different sensors. ▪ New algorithms (deep learning) that manage the operation of the guide.
Level 5	The car manages independently, without human intervention, any situation, even problematic.	▪ Sensors and technologies are seen as a single entity, integrated with each other and able to communicate. ▪ Presence of three modules: 1. algorithms that extract information from the collected data (about 1.8 GB per second) 2. operating system 3. cloud platform

As we can see from the table above, the overall objectives of an autonomous vehicle are:

- Perception of the surrounding environment;
- Planning, or the ability to take decisions, interacting with other agents, to define the path to be followed;
- Control, or the conversion of what is planned into actions.

Beyond the technical aspects, the most complicated problem about autonomous vehicles in Europe, as well as the rest of the world, is currently the bureaucratic one. All of the laws are based on pre-digital scenarios, but the Vienna Convention on Road Traffic (1968) governs road traffic on an international basis, to which individual countries' road codes are adapted, and it considers the mere presence of a person capable of controlling the vehicle. The first autonomous driving trials in Europe were made possible with the presence of a driver that could take control of the vehicle in case of emergency. Germany, the Netherlands, Norway, and Finland were among the first European countries to pass legislation on self-driving cars[2], and the European Union is currently considering similar legislation[3]. In this phase it is crucial to foresee the simultaneous presence of autonomous and traditional vehicles on the roads.

As for the infrastructure there is a large gap in development between European countries: the Netherlands, Finland, Norway, Sweden, Belgium and Austria lead the way. They have a very high number of charging points for electric vehicles (considering that most autonomous vehicles are electric), an excellent road quality with high level of ordinary maintenance. There are also several connected traffic lights that send their data wirelessly to the AVs. These countries already have excellent 4G coverage and good 5G coverage at different frequencies and on a large scale and a high speed of mobile connection. Furthermore, alongside technologies and infrastructures, these countries are focusing on policies linked to more sustainable mobility and less centred on the use of internal and private combustion vehicles.

The European Commission adopted a shared policy on intelligent cooperative transport systems (C-ITS) on November 30, 2016, allowing vehicles to connect with each other and with networks to use roads since 2019[4]. Furthermore, the European Commission created the C-Roads platform in 2016, which collects the activities of various member states on issues of linked, cooperative, and automated driving in order to make European roads safer, less congested, and with fewer harmful emissions, and, as a result, improve the economies of the various countries.

2.2 Smart infrastructures

The Autonomous Vehicle Readiness Indicator (AVRI) aims to evaluate the readiness of the countries for the introduction of autonomous vehicles under many aspects, also in order to provide support to public institutions and valid suggestions for improvement. It is based on four aspects:

- Policy and legislation;
- Technologies and innovation;
- Infrastructure;
- Consumer acceptance.

[2] https://assets.kpmg/content/dam/kpmg/xx/pdf/2020/07/2020-autonomous-vehicles-readiness-index.pdf
[3] https://www.europarl.europa.eu/RegData/etudes/STUD/2018/615635/EPRS_STU(2018)615635_EN.pdf
[4] https://ec.europa.eu/transport/themes/its/c-its_en

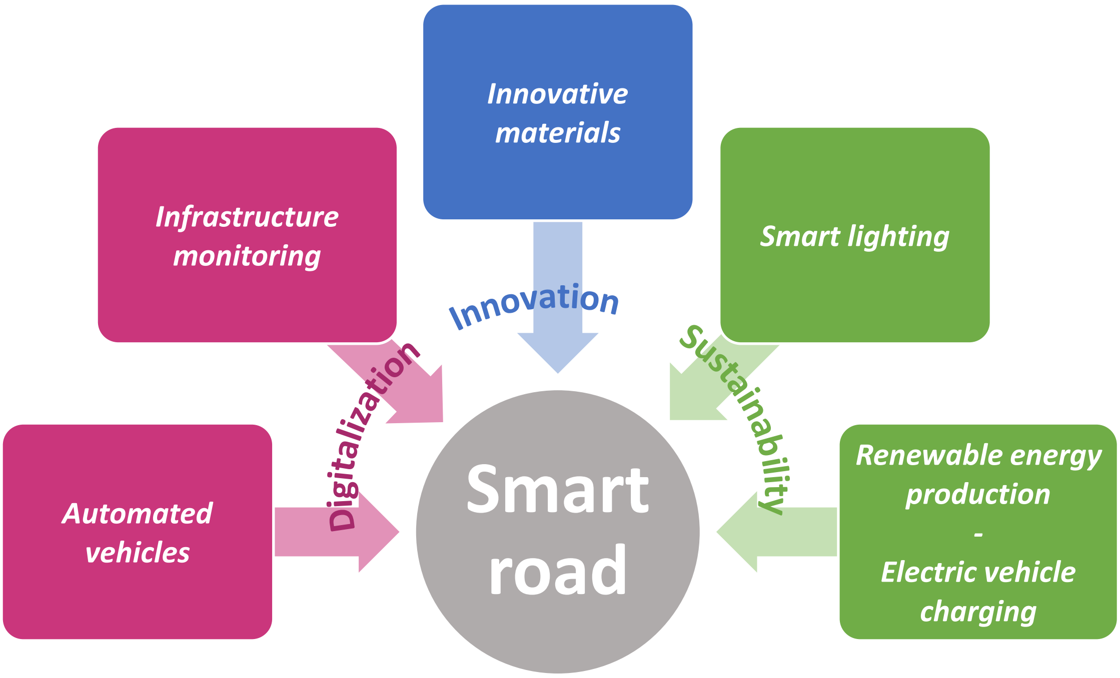
There is a clear link between achieving the best AVRI results and economic growth, but there are other essential factors to consider when assessing progress. In reality, all of the states with the highest rankings have governments that support the introduction of autonomous vehicles, even at a regulatory level, and that form commercial partnerships with the industry's leading providers, as well as excellent infrastructure networks and significant private investments in the sector and have already completed a large-scale test process with the help of the automotive industry.

A Smart Road can be described as the interaction of physical infrastructure (concrete, asphalt, tunnels, bridges, and road signs) with technical infrastructure (monitoring platforms, data and information processing models, and advanced services for infrastructure managers, the public administration, and road users), for which the digital transformation phase is aimed at producing monitoring platforms, data and information processing models, and advanced services for infrastructure managers, the public administration, and road users. It is also an infrastructure framework that aims to introduce monitoring platforms and data processing models in order to create a technical environment that facilitates the interoperability of next generation infrastructure and vehicles.

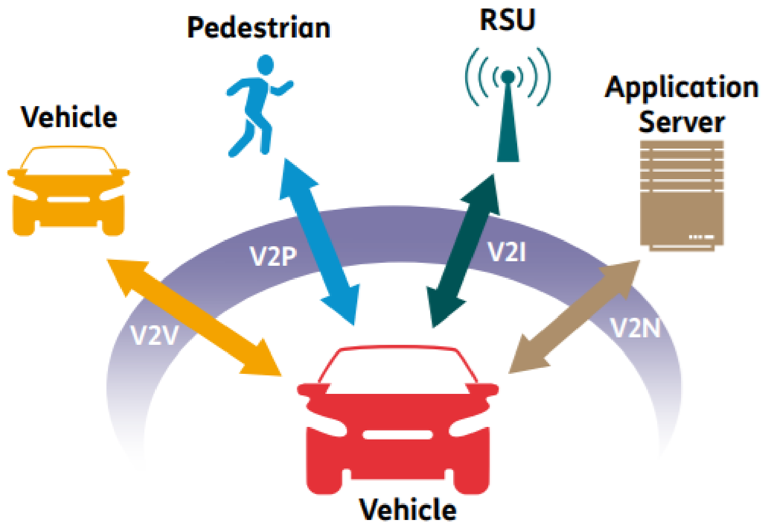
As a result, the Smart Road was created with the aim of increasing the sustainability of road transportation, enhancing comfort, and fostering an atmosphere conducive to the implementation of smart vehicles. In reality, in order to incorporate autonomous vehicles, infrastructures would need to be modified and modernized as well.

The interaction of smart vehicles with each other and with smart infrastructure is the focus of cooperative intelligent transportation systems, or C-ITS (the European ITS Platform is currently drafting the ITS Reference Handbook for Road Operators), which will make it easier for road users, traffic managers, and infrastructure managers to share and exploit previously untapped data. These systems result in improved road safety, more effective traffic control, lower CO2 emissions, and reduced driver stress.

In addition to the natural functional link with smart vehicles, the term "smart road " may have a wider sense, encompassing issues such as data transmission infrastructure, electricity and energy management, and the transformation of cities and territories into smart cities and smart lands as a digital infrastructure. In reality, until now, all technical advancements have been based on the side of vehicles, with no digital transformation of the roads. Other sensors that monitor the physical state of road maintenance or innovative self-healing materials that have a significant impact on the circulation of AVs as they guarantee the "physical integrity of the road surface and the static safety of the infrastructure can be installed in addition to all the digital technologies that enable self-driving vehicles to navigate. Smart roads may also include technologies for generating electricity from renewable sources, dynamic wireless charging of electric vehicles that travel through them, improving the energy efficiency of public lighting systems through smart lighting technologies that regulate light intensity in response to the passage of vehicles or other road users, and, in extra-urban settings, photoluminescence. All of these technologies, which can be built on or near highways, allow for more effective and efficient management, even from a distance, resulting in benefits for infrastructure managers.



2.3 Communication technologies: a review



source: "L'evoluzione dello standard 3GPP C-V2X" TIM technical newsletter 3/2018

2.3.1 V2V - Vehicle to Vehicle

This technology allows vehicles to share data (position, speed, acceleration, direction, steering angle, distance traveled, and trajectory prediction) with the goal of reducing traffic congestion and accidents by supplementing current radar and camera-based systems. It has a microprocessor, a GPS receiver, and a WLAN module that allows for short-range communication (300m) using the DSRC protocol. V2V technology can also be mounted on existing vehicles to detect traffic, lane, pavement, and weather conditions with the addition of additional sensors.

The fact that the vehicle information transmitted does not identify the vehicle or its driver is a strength of this technology, and technological solutions to prevent vehicle tracking and device tampering are possible.

2.3.2 V2P – Vehicle to pedestrian

Vehicle to pedestrian communication is a subset of vehicle to vehicle communication, in which the vehicle communicates with nearby pedestrians or cyclists, encouraging their identification and triggering an alert in the event of a collision danger. V2P can use a variety of monitoring methods (cameras, DSRC, infrared, infrastructure sensors, laser, mobile device ping, motion sensors, radar, or sonar) and can be configured in a variety of ways: it can be an on-board warning system vehicle or a handheld device used by pedestrians, or it can use infrastructure as an intermediary to provide a more precise prediction of pedestrian movements.

Notifications may be sent to either the car, only the pedestrian, or both at the same time. In the case of more vulnerable groups of road users (blind people, people in wheelchairs, etc.), V2P will become even more important in promoting their welfare. Several manufacturers are working on the integration of devices that can be installed on micro-mobility vehicles (bikes and scooters) as well as the standard that will be used to enable connectivity and thus improve safety.

2.3.3 V2I/I2V - Vehicle to Infrastructure/Infrastructure to Vehicle

The transmission of information from infrastructure to vehicles moving on the road is a communication scheme that helps vehicles to more easily and accurately distinguish and locate infrastructures (lane separators, road markers, road signs, and so on); this information complements that detected by the vehicles' cameras and LIDAR systems, enhancing the driving experience. In addition, thanks to this technology, the vehicle can receive and relay information on traffic, weather, and road conditions to the infrastructure. As a result, drivers are alerted to possible risks, which improves road safety.

Smart road signs are also powered by this technology, which allows drivers to forecast traffic conditions before leaving.

2.3.4 V2N – Vehicle to Network

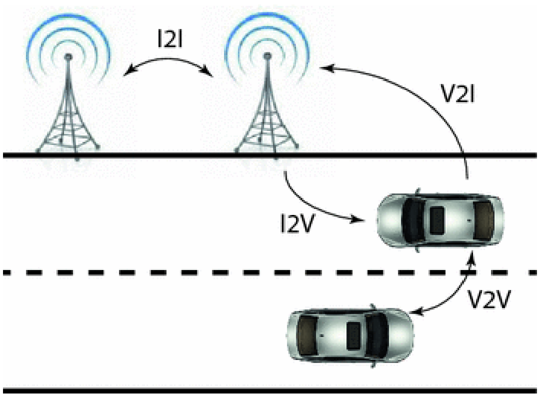
It is a vehicle-to-vehicle communication system based on cellular networks (LTE and E-UTRA) and a server that collects all data and information from vehicles, processes it using a decision engine, and decides the information to send to which vehicles or infrastructures, preventing the transmission of useless data. Until now, this technology has mostly been used for knowledge sharing in the fields of infotainment and telematics.

2.3.5 V2X – Vehicle to Everything

This technology, also known as Car-to-X, incorporates all of the previously mentioned communication schemes and ensures that each vehicle can connect with the entire device. Toll payments and the identification of free parking spaces can also be automated with V2X.

When all modes of transportation (trucks, buses, bikes, and bicycles) are equipped with these technologies, they will be much more effective.

V2X enables the development of VANET (Vehicular ad hoc Networks), wireless networks based on the concept of Mobile ad hoc networks (MANETs) that form spontaneously between vehicles and allow direct communication between them (V2V) as well as with the road infrastructure (V2I / I2V). The networking is built on the 802.11p standard and uses DSRC (Dedicated Short-Range Communications), which is an extension of Wi-Fi networks. 5.9 GHz frequencies have been allocated to VANET applications in Europe.



source: Shaikh F.K., Shah M., Shaikh B., Shaikh R.A. (2014) Implementation and Evaluation of Vehicle-to-Vehicle Traffic Congestion Detection. In: Shaikh F., Chowdhry B., Zeadally S., Hussain D., Memon A., Uqaili M. (eds) Communication Technologies, Information Security and Sustainable Development. IMTIC 2013. Communications in Computer and Information Science, vol 414. Springer, Cham.

5G is needed to enable these continuous over time and immediate communications. In reality, 5G reduces latency time (max 4 milliseconds) and increases download speed (20 gigabits per second) while consuming less energy and thus extending battery life.

3 Impacts of AVs

There are several viewpoints on how, when, and why autonomous vehicles could have some effects. Looking forward ten years, a variety of core topics were prioritized, discussed, and addressed in detail – the majority in different locations – based on the discussions in the first batch of workshops.

Among these, there are six main high-level macro drivers of change that are the subject of the most discussion and these are the areas where the impacts of CAVs planning will be grater. These are: impact of regulation, the less congestion, a rethinking of transportation planning, first/last mile topic, automated freight and data sharing.

Impact Of Regulation: The regions that will benefit the most initially are those with advanced policies and regulations that will foster the growth for AV deployment.

Less Congestion: While several AV proponents believe that reducing traffic congestion on the roads is a top priority, many also recognize that with mixed fleets in operation for many years, we may see a rise in urban traffic at first.

Transportation Planning: It may be important to reconsider a more flexible approach to planning in order for AV to have an effect. The benefits may be delayed due to a lack of cooperation between transit systems, urban planning, and potential solutions.

First/Last Mile Topic: Developing the ineffective first/last mile presents a significant opportunity in terms of health, electricity, and performance. Scooters, bikes, and small autonomous robots all play a role in urban environments.

Automated Freight: The huge automation of expressway trucks is a big business opportunity. Long-haul travel will be transformed, and it is the primary subject of legislation and trials at all levels of AV.

Data Sharing: In order to realize the AV vision, more and deeper data sharing is needed. Mobility brands will ultimately settle on V2X interaction protocols and therefore promote the use of open data sets.

There are other areas that contribute to cover a broad range of the autonomous vehicle landscape and reflect on the impacts.

Environmental and Social Impact: In certain cities, proving that autonomous vehicles are safer than alternative alternatives could be a requirement, while the benefits of AVs to society as a whole is a critical issue for widespread acceptance.

Crash Avoidance: Support for AV benefits from a political priority of reducing human-caused injuries and road deaths. Though ADAS provides advantages, the promise of major safety enhancements is critical.

LESS TRAFFIC, FEWER ROADS, AND LESS PARKING SPACES: Successful implementation of AVs as part of integrated public transportation systems can result in not only fewer vehicles on the road, but also the elimination of parking spaces and the narrowing of roads.

PUBLIC TRANSPORTATION SYSTEMS: As autonomous buses become more common, other mobility solutions would be needed to fill in the gaps. The primary criteria are security, versatility, scope, and interconnectivity.

SHARING RELUCTANCE: Since many people respect their privacy, support for a dramatic increase in ride-sharing might not be as strong as some expect. A priority is to rethink vehicle configuration for strangers traveling together.

ENVIRONMENTS UNDER CONTROL: Controlled environments have shown the first steps in AV and are slowly increasing. Airports, port terminals, warehouses, mines, and even dedicated highways all provide protected development zones.

CYBER SECURITY: With the threat of hacking, service's junk, vandalism, and data theft, businesses are looking for ways to make AVs more secure by implementing common methods for closed, collaborative systems.

REMOTE ASSISTANCE CENTRES: Staffed call centres oversee, support, and respond to all AVs in the event of an emergency. Many public transportation vehicles need remote human control in the absence of drivers.

INITIAL CONSUMERS: While AVs can have a significant benefit for those without affordable mobility – especially the young, elderly, and disabled – autonomy must be appealing to all users from the start.

COMMON STANDARDS: International standards and technologies that are widely used may be needed to drive global rather than regional AV adoption. A more fragmented approach would be taken without them.

DRONES FOR COMMERCIAL GOODS AND PEOPLE: Innovation in speedy drone delivery services has accelerated deployment in a number of places, but air-taxis might not be as common as many anticipate. The effect on a large scale is minimal.

ROBO-TAXI FLEETS: Robo-taxis are rapidly being seen as the future of passenger cars, with the potential to alter both travel habits and car ownership decisions. They're a big part of what MaaS has to offer.

These effects translate into concrete new approaches to design and execution of the works from the standpoint of planning.

The table below depicts the key infrastructure elements that must be given special consideration in their design and adaptation to enable autonomous vehicles to operate in hybrid traffic (composed of both human-driven and totally autonomous vehicles).

Infrastructure components	**Notes**
Signs and markings on the lane	*Self-driving cars need road signs that are simple, noticeable, and consistent. Furthermore, road signs are not universal in all countries (consider the United Kingdom's relationship to the European Union) and should be standardized.*
Digital communication	Sensors (magnetic loops, detectors, cameras, radars, ultrasound detectors, and so on) and an Internet link (4G / 5G / wi-fi / optical fiber) are needed for digital communication.
Communication of accidents and roadworks	*Accidents and construction projects alter the road layout and must be reported to the AV, which must be able to incorporate these changes in real time.*
The surface of the road	Autonomous vehicles must be able to "sense" the road surface, identifying horizontal signs to stay in the lane or holes and manholes to avoid them, and, if electric, they must be able to recharge themselves across it. The consistency of the road surface, as well as its ongoing maintenance, will be critical.
Parking	*The demand for parking spaces will decrease in a situation where shared autonomous vehicles are widely adopted, as cars will be idle for shorter periods of time. Furthermore, such vehicles would be able to park independently and closer to one another, resulting in a decrease in the number and size of parking spaces. It should be noted that GPS signal reception is often low or non-existent in underground parking garages, which has a negative impact on the use of AV-enabling technology.* *In multi-story parking garages, it is possible to reserve the top floor or open spaces for AVs, or installing repeaters or devices that aid orientation and navigation on the inside.* *Electric vehicle charging stations will be needed in more and more parking lots.*
Sidewalks / roadside	These features would need to be rethought in order for self-driving cars to be able to pull over to pick up or drop off passengers.
Service stations	*They have everything to do with the vehicle's power supply. With the proliferation of electric vehicles (most AVs are electric), more charging points or road sections that allow for dynamic wireless charging may be needed. This, on the other hand, has to do with potential EV battery growth scenarios.*

Intersections / roundabouts	While roundabouts are now thought to be safer in terms of preventing collisions, intersections will provide a higher degree of protection in the case of self-driving vehicles. Intersections will increasingly be needed to provide a viewpoint on city traffic coordination and overall management.
Mobility Hubs	*Mobility hubs, also known as intermodal nodes, would be needed to facilitate continuity in travel in various modes, with a preference for pedestrian and cycling mobility, as well as public and shared transportation.*
Port accesses / bridge crossings / tunnels / underpasses	These components have inherent characteristics that must be taken into account if autonomous driving is to be effective.

Many of these infrastructure changes and upgrades take a long time, so cities must be rethought and re-planned in the long run. The whole city will become "smart" and "green," with more land dedicated to pedestrian areas, green areas, intelligent management of public properties, and public services such as waste disposal, maintenance, and underground utilities, among other things.

Level 5 self-driving vehicles would not even need the infrastructure of the roads with external sensors to assist them in navigation from a safety standpoint; however, this increase in safety may come at the expense of efficiency, and some studies predict a slowdown in traffic speed and a consequent worsening of congestion because autonomous vehicles would drive more cautiously.

Digital infrastructures, on the other hand, which allow for the sharing of information with vehicles (V2I), can solve this problem and ensure greater productivity by coordinating the movement of vehicles in a particular geographic area through a centralized traffic management system. As a result, two distinct operational scenarios could be imagined: in rural areas, where road capacity is not limited, self-driving vehicles could rely more on their on-board systems, while in urban areas or on major highways, where there is a higher concentration of vehicles, it would be more important for managing bodies to invest in digital infrastructures.

As a result, the deployment of self-driving cars will not be limited to specific geographical areas (geo-fences) where the digital infrastructure has been developed, penalizing areas that cannot afford to install such devices. Although the road infrastructures must be held in excellent condition, particularly in terms of the condition of the road surface (absence of holes) and the visibility of horizontal and vertical signs, sophisticated or that have problems of another nature (for example, connectivity), the road infrastructures must be kept in excellent condition.

The exchange of urban planners should consist of combining different sources of data, exchanging information, and developing strategic synergies and plans in order to assess the potential impacts of autonomous vehicles on urban areas and integrate autonomous mobility solutions into urban planning in order to support the specific needs of a city and achieve common socioeconomic and environmental goals.

The parameters of impacts of autonomous vehicles for passenger road transport on urban development and relevant challenges for urban planning are listed in the table below.

Parameters	Impacts and challenges
✓ *Value of time, accessibility and location choice.* ✓ *Traffic and parking condition and land use.* ✓ *Infrastructure, networks and design.*	To contribute to urban development goals, an appropriate combination of AV solutions as private, shared, and/or public transportation is required. Opportunities for freeing public space and land use management in relation to the potential externalities of AVs. Autonomous vehicles' potential contribution to areas with reduced roadway capability and weak roadway features (e.g. historical centres). Opportunities for creative urban infrastructure design to help AVs and other road users, as well as integration of the AV network with the energy and telecommunication networks.

The parameters of potential integration of the AV concept with the sustainable urban development policy and relevant challenges for urban planning in Europe are reported in the following scheme.

Parameters	Impacts and challenges
✓ *Policy priorities at European level.* ✓ *Distinction of priorities at local level.*	Taking into account the full scope of AVs' social, economic, and environmental effects on urban growth. Combination of local characteristics, demands, patterns, and policy goals for urban development with the overarching sustainable development policy framework in order to choose the best options for AV deployment.

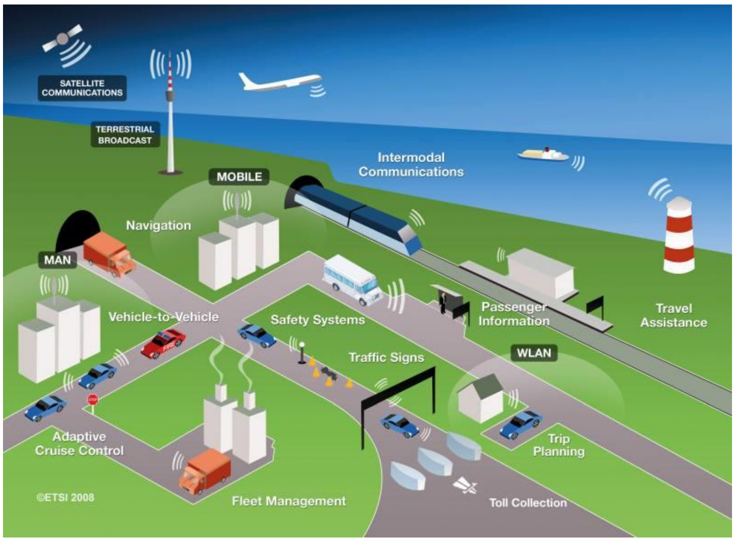
The parameters regarding the current lack of data and the enhanced data availability in the future due to the implementation of AVs and relevant challenges for urban planning in Europe are shown in the table below.

Parameters	**Impacts and challenges**
✓ *Lack of data for current planning purposes.* ✓ *Enhanced data for future planning purposes.*	With ad hoc surveys, it is essential to efficiently integrate existing data and information from different sources. Data exchange between research and urban planning. Strategic synergies for data sharing and knowledge transfer between European cities. Use of AVs as data sources to monitor their effect on the city and use big data to aid the overall urban planning process.

4 Key Enabling Technologies for Intelligent Transport Systems

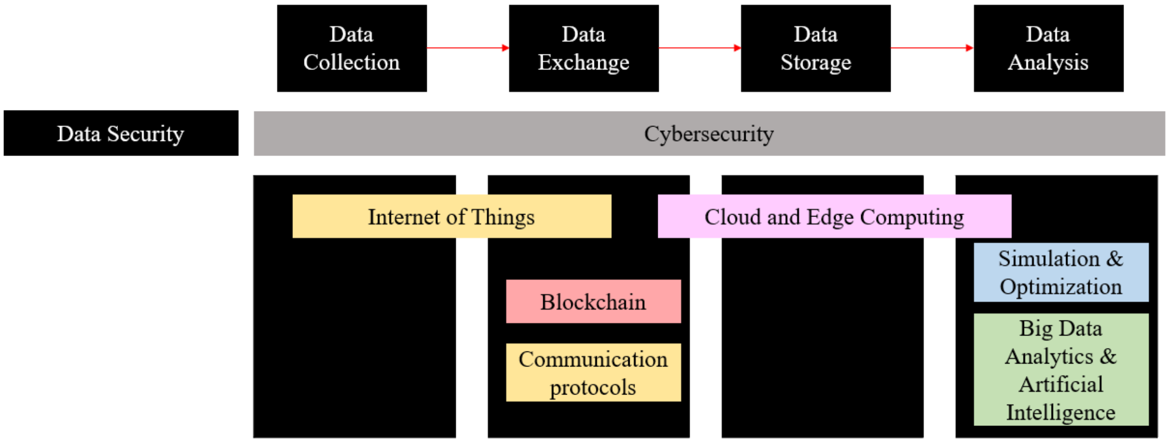
4.1 Introduction about Intelligent Transport System

The transport system management through digital technology is known as Intelligent Transport System (ITS) which comprise a set of innovative systems that use integrated communications and data processing technologies to improve traffic planning, increasing road safety, reducing traffic congestion, environmental emissions and improve emergency management. ITS adoption will facilitate the planning of mobility solutions for the short and long period. Thanks to ITS, it will be possible to simulate and monitor real-time traffic conditions and enable communication among vehicles and between vehicle and infrastructure. ITSs are not restricted to road transport, they also include the use of ICT for rail, water, and air transport.



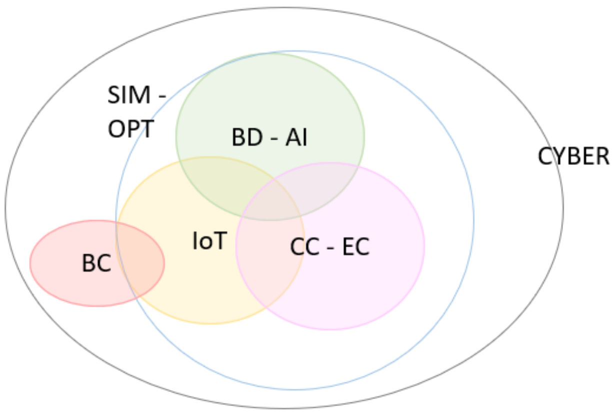
source: https://www.smart-industry.net/iot-smart-roads-paving-the-way/

To achieve these goals a set of technology will be introduced. Digitalization is just the first step towards a data-oriented approach. These technologies can be classified by the life cycle of data and services where they can be deployed: data collection, analysis, security, etc. Data collection is delegated to IoT technologies, sensors particularly. Such an amount of data opens the road for innovative approaches based on big data analytics and artificial intelligence; through these technologies, it is possible to infer information and knowledge from data. Cloud computing plays the role of infrastructure provisioning. The collected and analysed data enables simulation models and optimization techniques, which, in turn, allows engineers to extract new insights from data and visually present them. Blockchain easily allows coordination and sharing of data, documents and contracts in a secure and authenticated way. Finally, security -cybersecurity- is a crucial and traversal issue.



Technologies and data flow

There is not a one-to-one correspondence between technology and smart mobility solutions since these last ones depend on more than one integrated technology. Indeed, the key concept is *interconnection* which is the basis for the spread of these new mobility measures. Therefore, a more realistic scheme would be:



CYBER	Cybersecurity
SIM – OPT	Simulation – Optimization
BD - AI	Big Data Analytics – Artificial Intelligence
IoT	Internet of Things
CC - EC	Cloud Computing – Edge Computing
BC	Blockchain

Technologies interconnections

Indeed, these technologies are influenced by each other and they could not exist without the other. For example, IoT also includes some aspects related to data storage, cloud computing, and data analysis, big data analytics, and simulation would not exist without data collected from IoT sensors, stored in the cloud and processed by artificial intelligence.

Nevertheless, the first flow is used in this report, since it is more straightforward.

This synergic application of different technologies is boosting new mobility scenarios, involving logistic services, mobility information, info-traffic, inter-modality, flexible pricing, parking management, sharing mobility services, environmental issues, security, intelligent signals, etc.

Mobility as a Service (MaaS) has a crucial role in the technology application to foster more sustainable mobility in the future. It provides users with information on the optimal route to reach the desired destination and suggests multi-modal transportation services (possibly different from the private car). The service is highly customized and demand-oriented. It usually, also, offers other details such as the travel cost, required time, offering the chance of booking, buying e-tickets and validate them (in the same way among different providers, which is not so common today). Maas is introducing a new payment scheme such as "pay-as-you-go". Currently, it is applied as a centralised system that operates as an intermediary between providers and users, however, technology such as blockchain, internet of things, edge computing can support the change towards a decentralised system easily scalable and open to new providers. This can boost the efficiency of a smart city transportation supply and reduce negative emissions.

Smart vehicles are a piece of the smart mobility puzzle. Connected vehicles, or smart vehicles, are connected vehicles that communicate real-time information to the driver and other vehicles and the infrastructure. Automated guided vehicles (AV) are a subset of the connected car, i.e., being connected is a prerequisite for AV.

Autonomous vehicles are being improved thanks to the synergic application of several technologies. These vehicles must be equipped with high capacity, speed and reliable communication systems which enable the continuous data exchange among vehicles (vehicle-to-vehicle V2V), between them and the infrastructure (V2I), with pedestrians (V2P). Thanks to interconnection vehicle-to-everything (V2X), cars will share real-time data generated from the onboard sensors and the perceived environment. This will permit the autonomous coordination and synchronization among AVs, even in complex situations, boosting safety, efficiency and sustainable mobility.

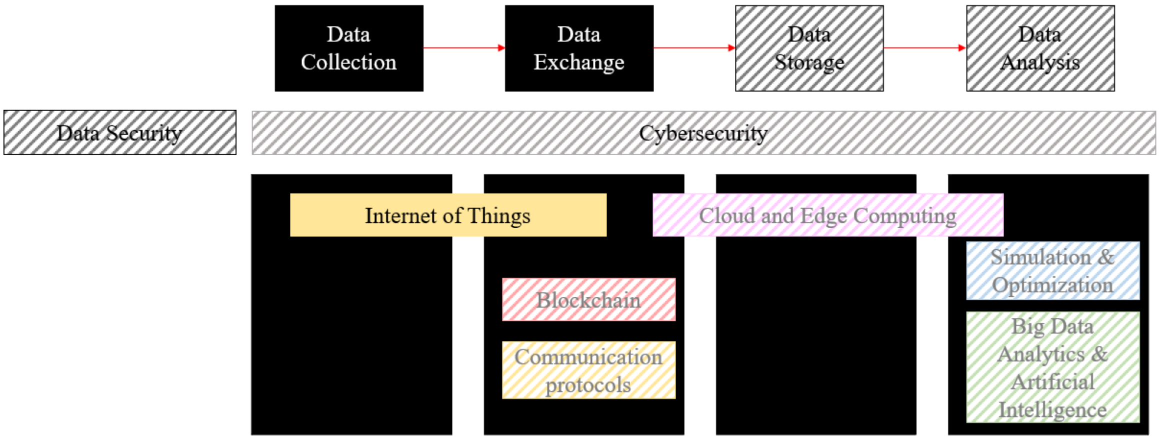
It will be better detailed in the following "Technology Factsheets", but all the technologies play a crucial role in the AVs spread.

The interconnection of technologies and the cooperation among AVs requires the support of a communication network able to connects all the involved objects. In Technology Factsheet 1 (IoT) a specific focus on the communication protocols is included.

Finally, it is important to mention that AVs can support the achieving of the traffic reduction goal only when integrated into a larger mobility system, otherwise, these vehicles can worsen the situation if they are used as private cars are today. It is possible to reduce traffic and, consequently, harmful emissions, only if the public transport is attractive and the different modalities (train, metro, bus, shared mobility, on-demand services) are integrated and there is a well-established set of facilities for walking and cycling. In this context, MaaS solutions can be very supportive.

4.2 Internet of Things IoT

4.2.1 Framework

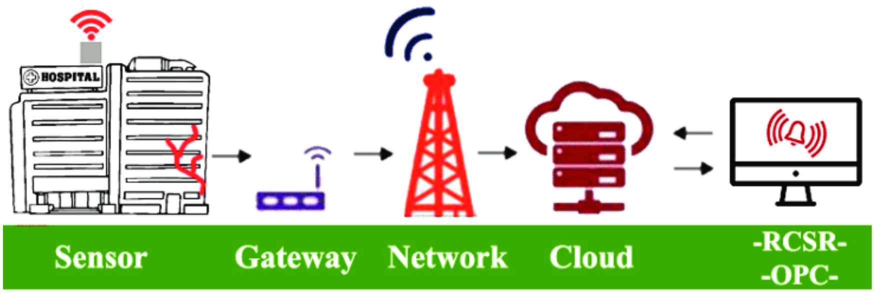


4.2.2 Technology Description

Internet of Things (IoT) describes a network of physical objects (things) intending to connect and exchange data with other devices or systems over the internet. To reach this goal, the "things" are embedded with sensors, software and other technologies.

The main elements which characterize the IoT architecture are:

- objects: software, hardware and IoT components (such as sensors, RFID, cameras, actuators, processors, etc.);
- network: connectivity to the network which joins the object to the cloud (protocols);
- control centre (cloud): application platform and systems for central storage, elaboration and exploitation of information from data, as well as communication and objects management.



source: Lamonaca, F., Sciammarella, P. F., Scuro, C., Carni, D. L., & Olivito, R. S. (2018, April). Internet of things for structural health monitoring. 2018 Workshop on Metrology for Industry 4.0 and IoT. 95-100. IEEE.

Gateways are hardware devices which act as "gate" between devices (sensors) and the cloud. They can manage data requests, event notification, check node connectivity and perform system integrity tests deploying IoT protocols.

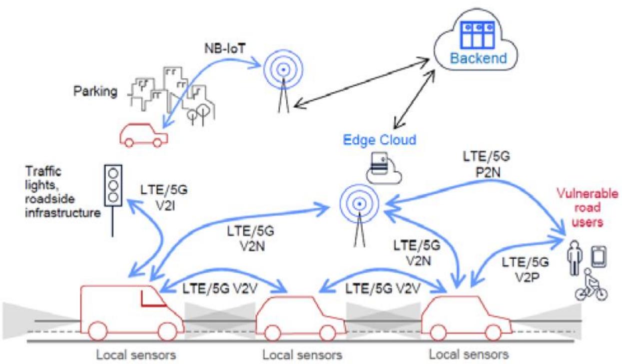
These objects are intelligent, "smart", since they have the following characteristics:

- self-awareness: they monitor specific internal parameters relative to their functions like identification, localization, status, the charge left in the battery;
- interaction with the surrounding environment: they can acquire data by measuring status parameters (sensing), flow parameters (metering), actuation (the ability of an object to follow given commands);
- data elaboration;
- connection (wired or wireless): to communicate the locally gathered information.

4.2.3 Technology applied to the Transport Sector

IoT applied in the transport context is known as Internet of Vehicles; it is a technology stack very similar to IoT where the smart objects are the vehicles themselves or the infrastructure's elements (traffic lights, traffic signs). IoT is directly correlated to the capability of vehicle and infrastructure to collect data and share this data, providing useful information for both citizens and traffic managers. Connected cars are also known as "automobile as a sensor" which permits the data exchange not only among vehicles (V2V communication) but also between vehicles and infrastructures (V2I), or pedestrians (V2P – V2X).

The joint application of IoV and road management tools enable the development of real-time traffic management systems. In fact, the latter integrate different technologies in order to enhance traffic flow and increase road safety. Real-time traffic data (from sensors, cameras, loops detectors, vehicles, signals, etc.) converge to a centralized transport management system where they are integrated and elaborated (cf. BD - AI) to support the decision-making process.



source: "Dalla guida autonoma alle reti V2X quali evoluzioni tenologiche per il settore dell'auto?" Report 2019-2020 Politecnico di Milano

Moreover, data collected from IoT sensors, both from the connected cars and from the infrastructure, enables the so-called intelligent intersections (cf. SIM-OPT). Intersections with traffic lights are usually retimed every five years, but this time gap can be too extensive in relation to the rapid changes in the traffic conditions. Thanks to data from the connected vehicle, from the signal controller units and local sensors, it is possible to automatize signal retiming. Indeed, traffic engineers own a huge amount of real-time data which can be used to control and manage intersections. This is enabled by big data analytics (cf. BD – AI) and algorithms that provide dashboards of information, allowing to monitor and adjust intersection much more efficiently and effectively than the manual alternatives (cf. SIM-OPT). The adaptive traffic signals can give intersection priority to pedestrian and cyclists or public transport, besides, of course, to the emergency vehicles.

IoT supports smart parking systems, indeed, IoT sensors help to collect location data and monitoring the occupancy of the parking lots, this information is transferred to a cloud gateway, processed and sent to the network server. Data is, then, presented to the drivers through an APP and, in this way, they can find out where the nearest parking spot is located. It shortens the search time and, consequently, increase the level of drivers' comfort.

Internet of Things also supports fleet managers and public transport companies. Indeed, through sensors and shared data, the managers can instantly know the maintenance needs of their fleet, vehicle localization and other precious information regarding their vehicles.

Another IoT application regard connected trucks which can send messages and information among themselves. This allows the creation of a "train of trucks" (platooning): the first vehicle communicates to those who follow him the optimal route, required speed and distances. Platooning increases the level of transport safety, smooths traffic flow and reduces CO_2 emissions and fuel consumption.

IoT is also an enabler technology for the presence of autonomous driving vehicles, since being connected is a prerequisite for this automobiles' category.

Furthermore, IoT can be applied for the structural health monitoring (SHM) of critical infrastructure (road, bridges, tunnels). SHM aims to identify, detect and characterize degradation and damage of infrastructure through the usage of sensors that monitor different parameters (temperature, humidity, stress, acceleration).

4.2.4 Impacts

IoT is a fundamental technology for connected cars and autonomous vehicle, as well as for real-time traffic management. It implies many benefits:

- the application of IoT offers drivers real-time information and alerts, significantly boosting the drivers' safety;

- real-time traffic data collection enables better traffic management and provides users with geo-referenced information regarding traffic, weather, road conditions, accidents, deviations, alternative routes in emergencies. This contributes to congestion reduction, saving time and avoid stressful situations for citizens;
- IoT applied to public transport can improve the service, providing real-time data on the bus localization, arrivals time to the users and it can also enable the preference of the green traffic light to the public transport;
- IoT supports the monitoring of limited traffic zones and, also, parking management is facilitated by real-time information exchanges between vehicles and parking infrastructure. This reduces the time needed to search for a free parking lot and, consequently, reduce CO_2 emissions;
- real-time data can be communicated to digital, dynamic and integrated signage, which adapts speed limits, safety distances and direction according to real-time needs. This increases safety;
- platooning helps reducing congestion, increase road safety and decrease negative pollutant emissions;
- IoT technology plays a crucial role in V2X and X2V communication, allowing data exchange between onboard sensors and the environment. These communications are crucial for the spread of autonomous vehicles;
- IoT, combined with AI can be applied for the Structural Health Monitoring (SHM) of roads, bridges, railways, etc (cf. BD -AI).

4.2.5 SWOT analysis

Strengths	Weaknesses
• increase road safety not only for drivers but also for pedestrians, cyclists; • reduce accidents; • decrease traffic congestions; • decrease pollution and energy consumption; • real-time traffic management; • support for freight vehicles, public transport services, transport logistics, deliveries, park management; • possibility of constant road monitoring and predictive maintenance application.	• necessity of extensive infrastructure renovation resulting in high capital investments’ need; • need for specific skills; • technology aspects (vehicle standardisation, unification of platforms and services).
Opportunities	**Threats**
• support for electric mobility (information on recharging stations along the way); • new source of revenue derived from data selling; • new business model based on data; • fertile ground for autonomous vehicles; • boost shared mobility due to the facilitation of data exchange; • new impetus for inter and multi-modality solutions due to the real-time data collected; • coordination with other initiatives in the wider context of a smart city.	• challenging public acceptance; • difficulties concerning the joint implementation of the technology among different infrastructures managers; • strong benefits are related to joint and widespread implementation of the technology, not isolated solutions; • uniformity lack at the European level; • absence of specific ethical and privacy regulation;

4.2.6 Applications

Smart Road Cortina 2021:
http://www.anaspercortina2021.it/smart-road-cortina-2021
https://www.ingenio-web.it/29756-a-cortina-la-prima-smart-road-di-anas-in-futuro-tremila-chilometri-di-strade-intelligenti
https://www.lastampa.it/motori/attualita/2021/02/04/news/a-cortina-debutta-la-prima-smart-road-quasi-100-km-di-strada-connessa-e-intelligente-1.39859904

C-Roads Norway
https://www.c-roads.eu/pilots/core-members/norway/Partner/project/show/test-project-6.html

Smart Road Netherlands
https://www.youtube.com/watch?v=mSPQLoYwikQ

Smart Parking Verona
https://smartparkingsystems.com/smart-parking-system/

Platooning (V2V and simulation)
https://blog.ptvgroup.com/en/city-and-mobility/platooning-microscopic-simulation/

Structural Health Monitoring:
Ponte Stura – viadotto del raccordo autostradale Torino-Caselle (Adicom Group e Anas)
https://www.adicomgroup.com/tag/viadotto-stura/

4.2.7 Tips/Requirements

- Nowadays, sensors are evolving, devices are smaller with increasing sensory, processing and communication capabilities and, at the same time, costs and energy conception are diminishing.
- Computing power is increasing and costs are lowering: IoT objects are becoming capable of hosting an Operating System (OS) to manage hardware, networking, updates, communications, security, etc. The presence of an OS dissociates the hardware from the software. This allows the applications to work on different devices and the same device to use multiple applications: multi-functionality is a core aspect of IoT.
- IoT applied in the mobility context requires high reliability and low latency.
- A dataset can be considered more reliable if originating from more than one source and/or different sensors. This is particularly crucial for connected cars and, even more, for autonomous cars. The situation can be better analysed by combining onboard data with data collected from the environment, infrastructure, weather, etc.
- The proliferation of data generated by autonomous vehicles allows the rethinking of the business insurance models. Pay-as-you-drive (PAYD) is a type of vehicle insurance whereby the costs are dependent upon the type of vehicle used, measured against time, distance and place. Drivers can have flexible premium fees according to the cars usage monitoring thanks to the sensors and intelligence systems.

4.2.8 Focus: communication protocols

Note: this focus is reported here since its strong relation with IoT, however, it is critical also for the other technologies. In order not to be redundant, it is reported only in this Technology Factsheet.

Protocols of communication can be classified into two big "families":
- short-distance communication;
- long-distance communication;

based on their extension and data transmission speed.

Belongs to the first typology: Wi-Fi, HaLow, Bluetooth Low Energy, to name but a few, while SigFox, LoRaWAN, 5G, Narrow-Band IoT belongs to the long-range protocols.

This last group is experiencing rapid evolution and international expansion.

Communication protocol	Short Range Network - LR-WPAN			Long Range Network - LP-WAN		
	Bluetooth Low Energy	Wi-Fi	ZigBee	LoRaWAN	SigFox	Weigthless
Range (km/m)	80 m	50 m	100 m/Mesh	2-5 km urban 15 km suburban 45 km rural	10 km urban 50 km rural	5 km
Frequency Band	2.4 GHz	2.4 GHz	868 MHz / 2.4 GHz	Various, Sub-GHz	868 MHz	Sub-GHz
Bidirectional	Yes	Yes	Yes	Yes	No	Yes
Data Rate	1 mbit- 3 mbit	11 mbit- 54 mbit	250 kbps	0,3-50 kbps	100 bps	30 kbps - 100 kbps
Node's quantity	Dozens	Thousands	Thousands	Millions	Millions	Limitless
Energy Consumption	High	High	Low	Low	Low	Low
Infrastructure	Node-node, Star, Tree	Star, Tree	Node-node, Star, Tree	Star	Star	Star
Standard	Bluetooth 4.0	IEEE 802.11	IEEE 802.15.4	LoRaWAN	No	Weigthless

IoT protocols – data from "Smart Road - La strada all'avanguardia che corre con il progresso" Anas Spa

Connectivity and short-range communication are crucial for autonomous cars development. Today V2X technologies are ETSI ITS-G5 standard (based on Wi-Fi) and the cellular technology C-V2X (based on 4G but evolving to 5G). 5 875-5 905 MHZ frequency bandwidth is dedicated to these technologies, according to the EU directive[5]. Nevertheless, these performances are not adequate for AVs, due to the latency, reliability and speed obstacles. The required frequency is of the order of millimetric-wave with Multiple Antenna Systems (MIMO) and complex algorithms. 5G standard will grant all these characteristics, being promising to support mobility applications.

4.2.9 Interactions with other technologies

Note: these interactions are bidirectional but to avoid being repetitive the first factsheet reports all the interactions, while the following ones present only those that are not already been discussed.

IoT – Big Data and Artificial Intelligence (AI): IoT sensors collect a huge amount of data related to vehicles, infrastructure, services, etc. Information, value and knowledge can be achieved from this data, only if processed. For this reason, Big Data analytics and AI algorithms, combined with IoT, are crucial to pave the way for the development of innumerable applications, enabling valuable services for clients. They can be supportive both to enhance vehicles performances as well as for traffic management.
Moreover, the autonomous guided vehicles technology is based on a mix of technologies including IoT and AI.

IoT – Simulation and Optimization: Simulation models can be developed based on real-time and update IoT data.

5 EUR-Lex 2008/671/EC

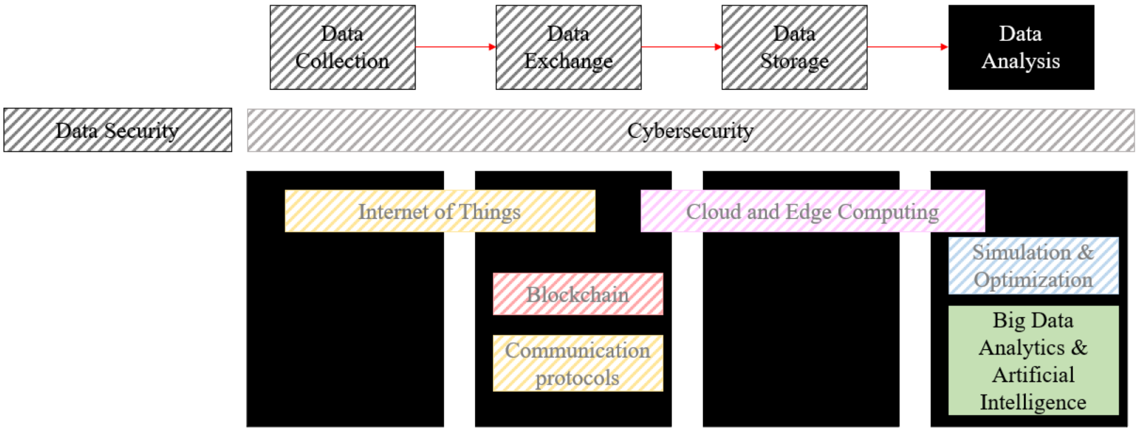
IoT – Cloud and Edge Computing: Cloud Computing is the technology that enabled IoT definition and diffusion. It can be considered the aggregator, storage and elaborator of the IoT data. Nowadays data elaboration can also be preliminary done thanks to Edge Computing technologies.

IoT – Cybersecurity: cybersecurity is crucial to preserve data privacy and prevent potentially highly dangerous attack from ill-intentioned.

IoT – Blockchain: blockchain can be applied to guarantee the security, integrity and authenticity of collected data.

4.3 Big Data Analytics and Artificial Intelligence BD - AI

4.3.1 Framework



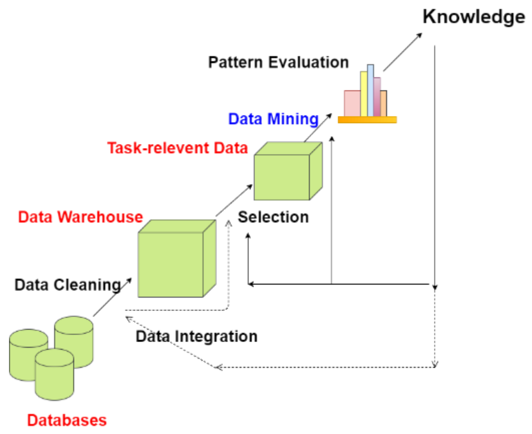
4.3.2 Technology Description

According to Gartner, big data is high volume, high velocity and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization. Smart objects (cf. IoT) gather a huge amount of data regarding themselves, their utilization, and the surrounding environment. This big data has to be mutated into precious information and new business opportunities. Big data is characterized by many features: the keys ones are reported in the "3V model": volume, velocity, and variety. The captured data is highly heterogeneous, and the amount is increasing arriving up to the zettabyte (YB 10 ^21) scale[6], moreover, current mobility solutions require real-time data, with a processing latency in the order of nanoseconds.

Big Data Analytics together with Artificial Intelligence (AI) algorithms support the process of value generation. Big Data Analytics is the process of collecting and analysing large data sets from traditional and digital sources to extract trends and patterns exploitable to support decision-making.

The Knowledge Discovering in Database (KDD) process is represented in the following scheme:

[6] https://www.bigdata4innovation.it/big-data/big-data-cosa-sono-come-usarli-ed-esempi/



source: http://www.lastnightstudy.com/Show?id=34/Knowledge-Discovery-Process-(KDP)

AI plays a crucial role to efficiently deal with a huge amount of data. AI algorithms are numerous, to name but a few, neural networks, naïve Bayesian classifier, support vector machines, Gaussian mixture models, decision trees, etc. AI and big data complement each other: AI becomes better, the more data it is given while big data are almost useless without algorithms to analyse it.

4.3.3 Technology applied to the Transport Sector

IoT (cf. IoT) enables the collection of a huge amount of data - big data - related to different transport aspects, from the vehicle locations to the payment or the supply utilization level. This data, if shared, can be transformed into information, knowledge and value thanks to big data analytics and AI algorithms. Moreover, these technologies enable to gather data from different sources (IoT sensors, devices, video camera, sound and vibration, electromagnetic fields, smart meters, magnetic loops, etc.) and merging them with other data sources such as census, households' characteristics, machines' certifications, etc. Then, the potential applications of this information are countless, from better supply and demand management to new adaptive mobility system to real-time needs and the optimization of the assets and infrastructure use. For example, IoT sensors related to vehicles and infrastructure can collect different real-time information and, AI can support the merging of this information and understand if pedestrians in the surrounding area are exposed to a dangerous situation and alerting them. Moreover, the collected big data can be used to improve the offered services, e.g., public administration can monitor the paths of bike sharing users to improve the service by adding new stations in highly popular areas or to build bike paths where needed.

Other potential applications of the joint leverage of IoT, big data analytics and AI algorithms in the mobility context are simulation and optimization (cf. SIM – OPT) and Maas platforms.

In order to plan a new mobility service or improve those which are already existent, transport demand data is critical. This data is precious for a correct definition of new mobility scenarios, but its collection is very time and money consuming. Big Data captured by devices, sensors, vehicles can be very supportive to collect speed, density, volume data about the traffic/pedestrian flow and logistics and to generate the OD matrices. This big data can be used to formulate, calibrate and validate a simulation model. Through AI it is possible to simulate future scenarios to support mobility planning (cf. SIM-OPT).

Maas (mobility as a service) is a type of service that enables users to plan, book and pay for their travel through a unique platform. MaaS offers citizens mobility solutions based on their real needs, suggesting solutions based on live data, boosting solutions different from private vehicle usage. These platforms engage (public and private) transport operators but also parking managers, weather forecasts, electric recharging managers, etc. The services are provided to the travellers thank the real-time data collected by the IoT sensor, analysed by the AI algorithms.

Traffic control is not a new practice, however thanks to big data the issue can be treated not only through traditional approaches but also through new instruments: sensors automatically collect data and specific algorithms process it. For example, measurements from different sensors, such as GPS navigators or mobile phones offer the chance of analysing the use of transport infrastructure and the travel mode by the customers at a fine-grained temporal scale and spatial resolution. Moreover, thanks to the new technologies the collected data can be matched with new data sources, e.g., geo-located data from social media or open data.

AI and machine learning can also be applied for predictive maintenance, for example, public transport operators can constantly monitor their vehicles and operate predictive maintenance with costs and resources reduction and an increase of the satisfaction level for the service's users.

Furthermore, thanks to sensing techniques, big data analytics and machine learning it is possible to improve the predictive maintenance of connected cars, by identifying the correlation between multi-sourced data.

Autonomous vehicle (AV) and artificial intelligence are strongly correlated. AI can cover the following roles concerning AV:

- AI can be implemented in the connected vehicles' devices to boost their functionalities. This enables immediate data processing and the possibility of making autonomous decisions;
- AI simplifies the interaction between driver and vehicle through voice-activated, e.g., the transmission of information about the vehicle state, mail reading, search of a point of interest (hotel, restaurants, shops etc.) in the surroundings;
- AI can support traffic management in a smart city context, e.g., it can define the vehicle priority, prevent accidents and avoid road congestion.

These three solutions are not mutually exclusive, but they have to be developed in a synergic way to achieve better results and to fully exploit the AI potentiality.

4.3.4 Impacts

Big data analytics and artificial intelligence support the process of knowledge development from the collected data; in the mobility context, this results in numerous benefits, such as:

- better services for the citizens, e.g., Maas, information platform real-time update;
- support to the mobility managers and traffic planner, e.g., through real-time simulation, it is possible to provide a better service for citizens, this fact results in a reduction of costs and resources for the Municipality/road operators, as well as a reduction of the environmental emissions and traffic congestion;
- boost structural health monitoring: indeed, data from IoT sensors can be merged with data collected on the field through traditional techniques, historical data and models thanks to appropriate algorithms; consequently, this allows to reduce monitoring costs, increase safety and longer life spans;
- development of autonomous cars (level 4 or 5);
- improve predictive maintenance of connected cars: this implies numerous benefits since drivers are immediately warned before failure occurs and this brings to lower repair frequency and lower maintenance costs. Furthermore, automakers are capable of identifying the fault pattern of particular equipment of a given car model. It thus provides a feedback loop that enables automakers and dealer to improve quality and customer satisfaction.

4.3.5 SWOT analysis

Strengths	Weaknesses
• establishment of new services for the citizens; • increase in the services' quality level; • support for traffic management and real-time decisions making; • decrease in pollution and energy consumption.	• privacy issues, particularly in relation to geo-localized data; • economic aspect for technologies development; • need for highly specialized human resources.
Opportunities	**Threats**
• new source of revenue derived from data selling; • new business model based on data; • boost of sustainable mobility solutions (multi-modal mobility, shared mobility); • fertile ground for autonomous vehicles; • coordination with other initiatives in the wider context of a smart city.	• being connected cyber-attacks might affect the entire system; • absence of specific ethical and privacy regulation.

4.3.6 Applications

Delivery robot
https://www.economyup.it/retail/robot-per-le-consegne-cosa-fanno-come-funzionano-e-gli-esempi-nel-mondo/
https://www.youtube.com/watch?v=-ektnKdu2i8

Structural Health Monitoring:
Ponte Stura – viadotto del raccordo autostradale Torino-Caselle (Adicom Group e Anas)
https://www.adicomgroup.com/tag/viadotto-stura/

Demand data acquisition - Movision
https://www.movesion.com/en/mobilitycity/

4.3.7 Interactions with other technologies

Big Data Analytics and Artificial Intelligence (AI) – Internet of Thongs: cf. IoT

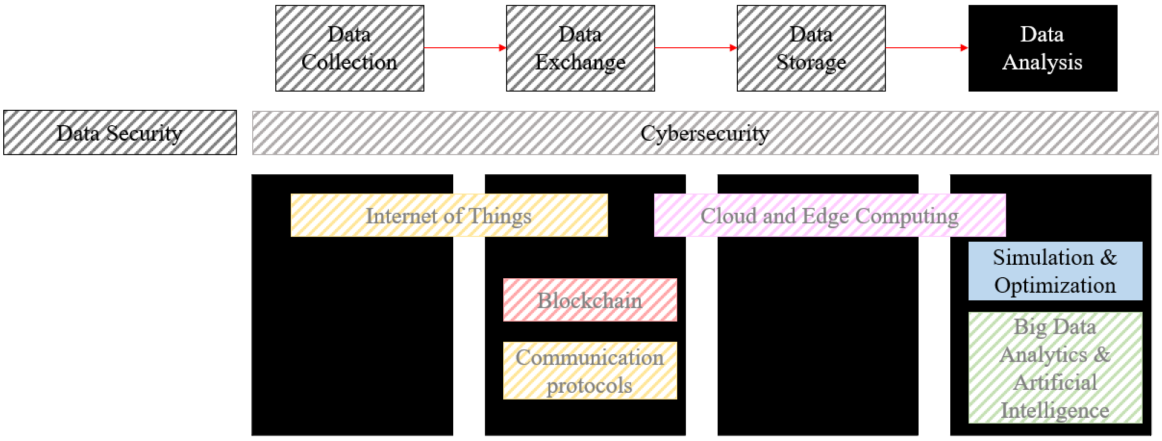
Big Data Analytics and Artificial Intelligence (AI) – Cloud and Edge Computing: Data from different sources can be exploited by different AI techniques via Cloud technologies.
Nowadays the growth of computing power installed within connected objects provides them with a higher autonomy in decision making, shifting the collected data processing phase to a local level. This enabling the sending of already processed data to the cloud or assigning to the cloud only specific situations which require a centralized and coordinated overview of the system.

Big Data Analytics and Artificial Intelligence (AI) – Cybersecurity: cybersecurity is crucial to preserve data privacy and prevent potentially highly dangerous attack from ill-intentioned.

Big Data Analytics and Artificial Intelligence (AI) – Blockchain: both enable MaaS services.

4.4 Simulation and Optimization SIM – OPT

4.4.1 Framework



4.4.2 Technology Description

Simulation is a widely used tool that supports the planning process, it re-creates real-world processes in a controlled environment, enabling experimentation in a safe environment. It is strategic for investigating ex-ante the effects deriving from planning changes without disturbing the real world, with consequent time-savings, expenditures reduction and security enhancement. Moreover, thanks to simulation it is possible to explicate complex scenarios (based on mathematical models) also to a non-technical audience (politicians, citizens, investors) and to support decision-makers. Simulation allows the engineer to explore different solutions, but optimization is crucial to define the most efficient solution also considering multiple and contrasting goals. Optimization supports the designer in the individuation of the Pareto solutions and, among them, of the most efficient solution.

4.4.3 Technology applied to the Transport Sector

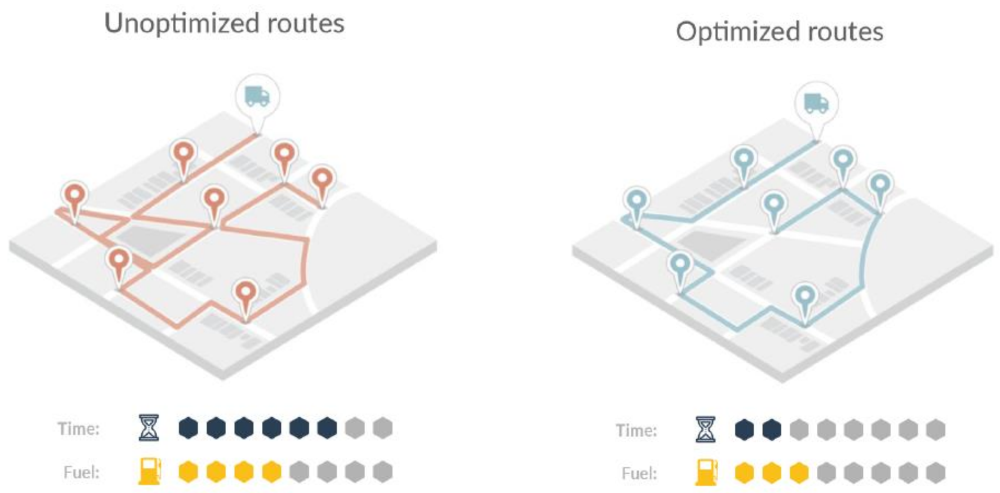
Simulation can be applied in a wide range of situation in the mobility context. Traffic simulation is a mathematical model of the transportation system through the application of specific software to support both planning and operational phases. It enables the study of very complex systems (too complicated for analytical or numerical treatments) and makes it possible to explore the solutions visually. Traffic simulation aims to better understand and model an efficient transport network, reducing congestion levels. Traffic reacts in a very complex and non-linear way according to many variables related to the interactions among different agents. Nowadays traffic models can be real-time updated thanks to IoT (cf. IoT) and big data analytics and artificial intelligence (cf. BD – AI) and these models can forecast traffic conditions and manage traffic demand. Simulation allows to predict the system behaviour and to do a “what-if” analysis.

Understand the behaviour of a complex system such as those with autonomous and traditional vehicles together and the co-existence of bicycle and pedestrian can be handled with simulation models. The problem is very challenging since there are numerous different actors, someone interacts with each other, the number of potential agents’ combinations and their interactions is exponential, the system evolves rapidly, and several possible perturbations may occur. An intelligent mobility management system can be developed thanks to the real-time data collected, using this information to coordinate travel modes, traffic signals, street infrastructure to reduce congestion and encourage alternative modes to the private vehicles.

Moreover, simulation and optimization jointly can be applied to support engineers in the definition of new mobility services to define the best balance between supply and the supposed demand. Big Data tools and analytics support optimization techniques that deal with multiple and contrasting objectives (minimisation of traffic congestion, minimisation of environmental impacts, demand satisfaction, etc.).

Intersections with light traffic are usually retimed every five years, but this time gap can be too extensive compared to the rapid changes in the traffic conditions. Moreover, thanks to the data from the connected vehicle, from the signal controller units and local sensors (cf. IoT), it is possible to evaluate and prioritizing intersections and to automatize signal retiming. Indeed, traffic engineers are in possession of a huge amount of real-time data which can be used to control and manage intersections. This is supported by big data analytics and algorithms (cf. BD – AI) which provide dashboards of information, allowing to monitor and adjust intersection much more efficiently and effectively than the manual alternatives.

Simulation and optimization can also support fleet management and logistic, facilitating scheduling and maintenance. They permit the fleet manager to effectively handle transportation resource planning, maximize transportation loads, minimize costs and calculate the probability of traffic cost overruns. As a safe environment for experimentation, it allows discovering potential difficulties ahead of time. Thanks to specific software it is also possible to optimize the routes for delivery with consequent time and money-saving.



source: https://routific.com/

Optimization is also part of the MaaS platforms, enabling the chance to suggest the optimised route and the trip which reduce users time spent to reach the destination, costs and avoid private car usage.

4.4.4 Impacts

Simulation and optimization:

- improve traffic management: this consequently reduce negative emissions and traffic congestion, increasing road safety;
- support the planning phase before the introduction of new mobility solutions. It allows the designer to test different scenarios to evaluate and compare their performances;
- retiming signals more frequently according to the traffic evolution over time and, consequently, limiting the congestions and reducing traffic delay and greenhouse gases emitted. Better intersection performance impacts also the citizens quality of life since they waste less time on traffic, experiences less stressful situations and increasing their productivity. Furthermore, it protects vulnerable road users such as pedestrians and cyclists;
- possibility of suggesting the best path for reaching the desired place, using means of transport alternative to the private vehicle; this consequently reduce $CO2$ emissions;
- assist fleet managers and logistic operators;
- route optimization reduces negative emissions, km travelled and saves drivers' time.

4.4.5 SWOT analysis

Strengths	Weaknesses
• Improve traffic management and consequently reduce congestion, harmful emissions, time spent travelling, energy consumption; • support designer in the planning phase before the introduction of new mobility solutions; • enhance traffic management and real-time decision making;	• Economic aspect for technologies development (very expensive software); • need for highly specialized resources.
Opportunities	**Threats**
• fertile ground for autonomous vehicles; • coordination with other initiatives in the wider context of a smart city.	• being connected cyber-attacks might affect the entire system.

4.4.6 Application

Piemonte real-time traffic monitoring
https://www.ptvgroup.com/fileadmin/user_upload/Products/PTV_Optima/Documents/5T_ITA.pdf

Oslo transport model
https://blog.ptvgroup.com/en/city-and-mobility/oslo-study-autonomous-vehicles/

City digital twin to improve traffic management
https://blog.ptvgroup.com/en/city-and-mobility/digital-twins-urban-mobility/

Roundabout simulation – AnyLogic
https://cloud.anylogic.com/model/b00c4c74-9f65-4fdf-9c27-0212db1e0bf6?mode=SETTINGS

Ship deliver simulation – AnyLogic:
https://cloud.anylogic.com/model/3a449f36-be23-4431-98d4-4d8f8f3b414c?mode=SETTINGS&tab=GENERAL

Intelligent Intersections – Parsons
https://www.parsons.com/smart-cities-challenge/

Enhance intelligent urban road transport network and cooperative systems for highly automated vehicles - Maven
http://www.maven-its.eu/

Logistic GIS - Tellus
https://tellus.it/

Route optimizer - Routific
https://routific.com/

4.4.7 Interactions with other technologies

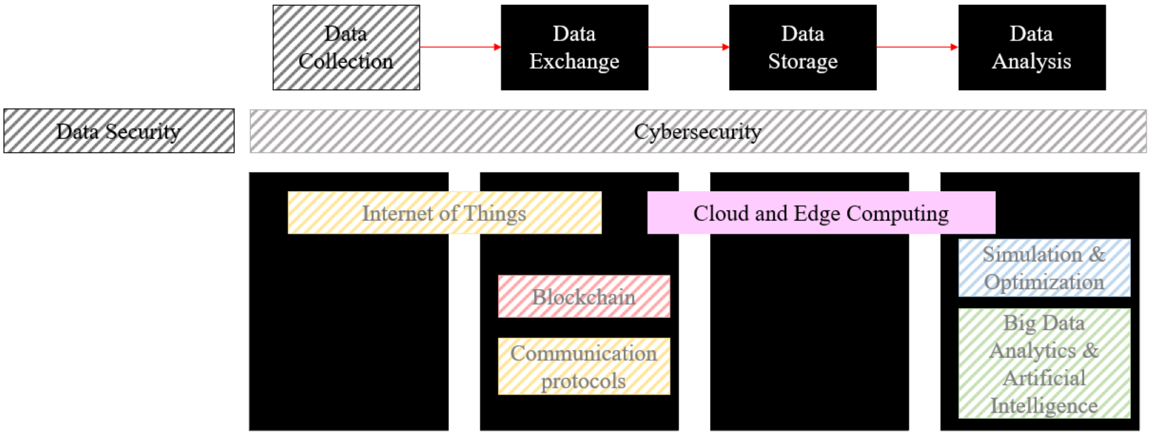
Simulation and Optimization – Internet of things: cf. IoT

Simulation and Optimization – Cloud and Edge Computing: cloud computing is worthwhile because of the huge amount of data needed for a real-time simulation model and the application of optimization algorithms.

Simulation and Optimization – Cybersecurity: cybersecurity is crucial to preserve data privacy and prevent potentially highly dangerous attack from ill-intentioned.

4.5 Cloud and Edge Computing CC-EC

4.5.1 Framework



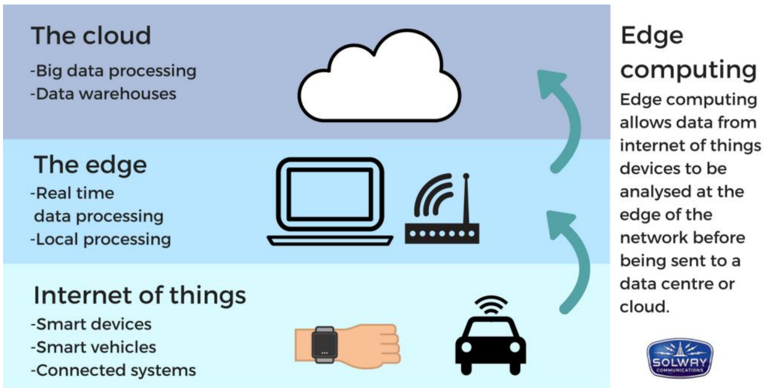
4.5.2 Technology Description

Cloud computing is the delivery of computing services (servers, storage, databases, networking, software, analytics), and intelligence, over the Internet, "the cloud", to offer faster innovation, flexible resources, and economies of scale. It is a paradigm for the IT resources provision on request via Internet, it assures the data availability for everybody, everywhere, through on-demand models. It also allows on-demand delivery of database storage, computer power and apps.

There are different types of cloud services: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Serverless Computing, Software as a Service (SaaS).

Cloud services can be public, private or hybrid.

Edge computing is an evolution of cloud computing based on real-time de-centralized data elaboration. This data is elaborated near where it is achieved with reduced bandwidth consumption. So, only the more complex elaborations are done in the datacentre thanks to Big Data Analytics and Artificial Intelligence algorithms (cf. BD – AI). Cloud and Edge computing are complementary technologies, which enables the creation of IoT networks.



source: https://www.solwaycomms.com/edge-computing/

4.5.3 Technology applied to the Transport Sector

Cloud Computing has transformed many different contexts, included traditional transportation services. Cloud services include the storage of data, back up, data analysis (cf. IoT and BD-AI), but also sharing resources, delivering software on demand and allowing the development of intelligent models to provide valuable insight from the collected data. They are located in distributed datacentres over a network such as the Internet.

Cloud-based urban control systems are emerging to optimize traffic control, taking advantages of all the information achieved through the IoT sensors from vehicles, infrastructure, and the environment.

Cloud computing, together with Internet of Things (cf. IoT) provide useful services also for public transport operators; they can use these technologies to share information on their fleet, vehicle's diagnostics, passengers count, using the network. If their fleet is connected, they can access real-time every crucial information regard the vehicles, receive automated alerts, and keep track of the maintenance needs of the vehicles. Moreover, they can use this information to improve the service provided to citizens, offering real-time updates on their route, delay, promotion, etc..

Modern cars are progressively equipped with an outsize quantity of sensors, actuators and communication devices (cf. IoT) and they can exchange data among them (V2V communication) and with the infrastructure (V2I). Cloud computing is essential to store and elaborate this huge amount of data. It is used for implementing intelligent transportation systems and to enhance communication.

Cloud Computing is part of autonomous vehicle technology. Through cloud exploitation, vehicles will be able to communicate with one another to prevent accidents, update traffic information and maps. A vehicle in the cloud would be able to receive updates via the manufacturer that could add additional cloud-based services. The cloud will also be able to automatically schedule maintenance checks and alert the user when it is time for the car to be taken in. In the future, vehicles will be also able to drive themselves to be repaired without the driver’s intervention. All the data collected by cars and infrastructure can be elaborated in the cloud.

Edge computing reduces the latency that is crucial for autonomous vehicles spread. These milliseconds gained allow to take vital decisions in a very short time. On these vehicles, mini calculators are installed on board to interact with the IoT sensors and elaborate huge data flow real-time.

Finally, Cloud Computing applied to logistic rises the concept of LaaS – Logistic as a service, i.e., all the different actors involved in the supply chain can use the same cloud platform, with different access authorization levels, and share information in a rapid e secure way (cf. BC). Cloud computing assures real-time visibility of shared information and interactive management. Furthermore, it offers a reliable and flexible environment to synchronize tools and services and notify customers of possible delays. LaaS can amplify its benefits, being integrated with a route optimization software (cf. SIM-OPT).

4.5.4 Impacts

Cloud Computing is a key technology for the development of autonomous vehicles technologies and enables several services such as:

- the creation of a huge datacentre with the IoT data collected on vehicles, infrastructure and environment;
- data storage and back up;
- data analysis and models creation exploiting high computing capacity;
- delivering software on demand available everywhere for everyone.

Edge computing eliminates the delay in sending data to the cloud but processes some data immediately; it improves speed and reliability which are particularly crucial for autonomous guided vehicles and to speed up the decision-making process.

4.5.5 SWOT analysis

Strengths	Weaknesses
• eliminate capital expense; • make it possible to access unlimited resources instantly; • always upgraded to the latest version; • can be scaled up elastically; • allow real-time control over critical processes, increasing efficiency; • enhance communication (V2V, V2I, V2X) and road safety; • make data backup, disaster recovery and business continuity easier and less expensive; *Edge computing* • reduces network latency;	• Potential attacks by hackers; • Security risks; *Cloud Computing* • Communication delay with the centralized data centre (crucial for autonomous vehicles)
Opportunities	**Threats**
• fertile ground for autonomous vehicles; • coordination with other initiatives in the wider context of a smart city.	• being connected cyber-attacks might affect the entire system; • lack of specific ethical and privacy regulation.

4.5.6 Application

Logistics – Data Cloud (King Transport)
https://cloud.google.com/customers/kings-transport

Transport for London
http://d0.awsstatic.com/analyst-reports/MWD_AWS_TFL_Case_Study_Sept_2015.pdf

Cloud Transportation Software
https://www.intellias.com/cloud-transportation-software/

4.5.7 Interactions with other technologies

Cloud and Edge Computing – Internet of Thing: cf. IoT

Cloud and Edge Computing – Big Data Analytics and Artificial Intelligence (AI): cf. BD - AI

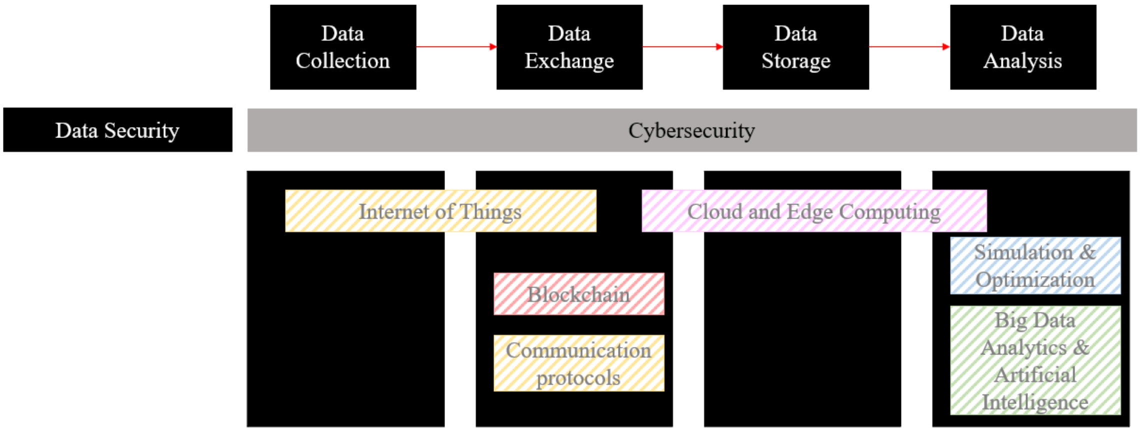
Cloud and Edge Computing – Simulation and Optimization: cf. SIM - OPT

Cloud and Edge Computing – Cybersecurity: cybersecurity is crucial to preserve data privacy and prevent potentially highly dangerous attack from ill-intentioned.

Cloud and Edge Computing – Blockchain: Blockchain can be provided via the cloud; Cloud computing technology supports multiple services together on a single platform. In this way, all the customers can access the platform and manage services and operation through blockchain. Moreover, edge computing can support blockchain-based MaaS since the power of computing and resources are distributed to different transportation providers at the edge of the network in a decentralized way.

4.6 Cybersecurity CYBER

4.6.1 Framework



4.6.2 Technology Description

Cybersecurity is a set of IT technologies aiming at protecting IT assets in terms of availability, confidentiality and integrity, i.e., it contrasts attacks that maliciously attempt to circumvent protection measures. Cybersecurity deals with the countermeasure to avoid, detect, counteract or minimize the risk related to an attack on physical properties, information, computer systems or other assets.

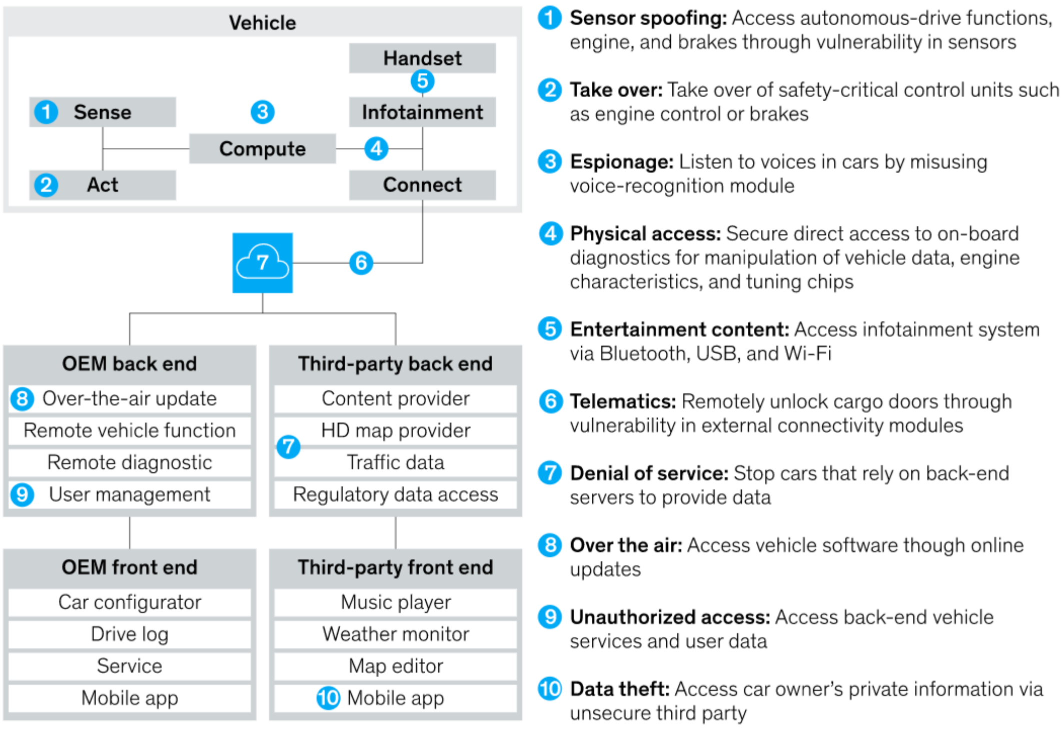
Data security and privacy are key issues that need clear legislation and a legal framework to support them. Today data access and exploitation remain unregulated. Cybersecurity standards need to be agreed upon to define a minimum-security embedded in the hardware, for software and connection.

EU data protection law (EU 2016/679 art.25) introduces two important concepts: security by design and by default. The first one means controllers must integrate data protection from the design stage and throughout the lifecycle. The latter refers to the fact that controllers should implement appropriate technical and organizational measures.

4.6.3 Technology applied to the Transport Sector

Thanks to IoT (cf. IoT) a huge amount of data can be collected and stored and analysed in the cloud (cf. CC-ED). Like other cloud-based products, data is exposed to hackers' attacks. Cybersecurity is crucial for cars that are connected, as well as for centralized traffic management and the online mobility services offered to citizens.

Today's cars have up to 150 electronic control units and about 100 million lines of code. Experts expect to increase this value to 300 million lines of code by 2030[7]. It generates numerous chances for cyberattacks with hazardous effects for users and also for car manufacturers and infrastructure managers. Potential cyber risks are reported in the figure:



source: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-for-cybersecurity-protecting-the-connected-car-in-the-era-of-new-regulation

Potential damage related to a sudden attack on autonomous vehicles during the journey is measureless.

Also, privacy is a very stringent security requirement for transport smart applications, particularly concerning the geo-localised data and content shared among users due to the connected devices.

4.6.4 Impacts

- Cybersecurity boosts the spread of digital technology in the transport sector, particularly in relation to autonomous and connected cars.
- It is a mandatory prerequisite for all the other technology (cf. IoT, BD – AI, SIM-OPT, CC-EC, BC).

[7] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-for-cybersecurity-protecting-the-connected-car-in-the-era-of-new-regulation

4.6.5 SWOT analysis

Strengths	Weaknesses
• protect users, citizens, as well as car manufacturer, traffic managers, public transport operators, road managers, etc.; • increase of the services' quality level.	• need for highly specialized resources.
Opportunities	**Threats**
• prerequisite for autonomous vehicles; • fertile ground for shared mobility, inter and multi-modality solutions, Maas, coordinate traffic management, other smart city initiatives.	• lack of cybersecurity-centre culture; • the automotive industry lacks cybersecurity standards; • automotive players do not always consider cybersecurity along all the car lifecycle (also after it is sold to customer); • different cybersecurity regulations among different countries.

4.6.6 Tips/Requirements

"Security is a process, not a product" (Schneier B. 2020).

The security requirements and principles for connected vehicles are:

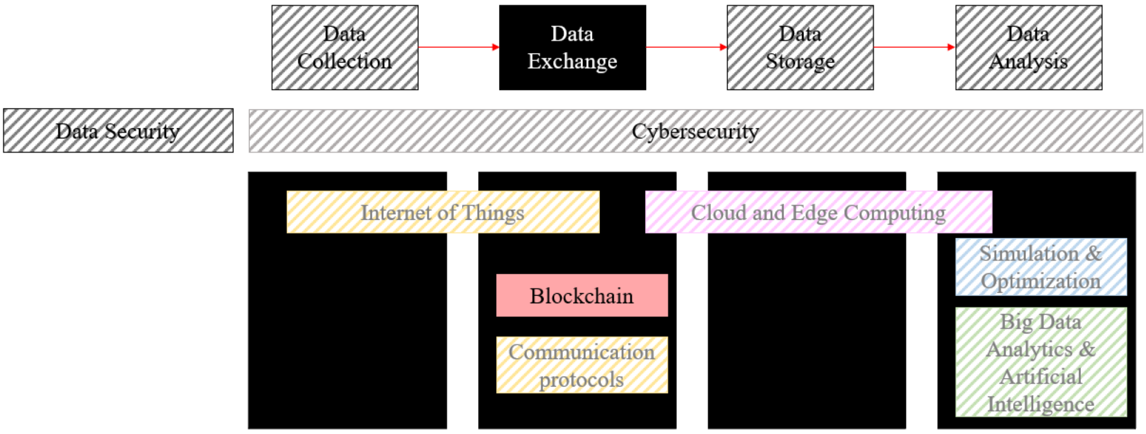
- data authentication: the shared information must be univocally associated with the id of the generator car;
- data integrity: share data must be correctly received;
- data confidentiality: data must be protected, and a secret transmission must be assured;
- access-control: every involved entity must be able to assess the services for which it is enabled to;
- data non-repudiation: any vehicle can deny the id to another vehicle;
- availability: communication among vehicles must be always available.

4.6.7 Interactions with other technologies

Cybersecurity is fundamental for all other technologies.

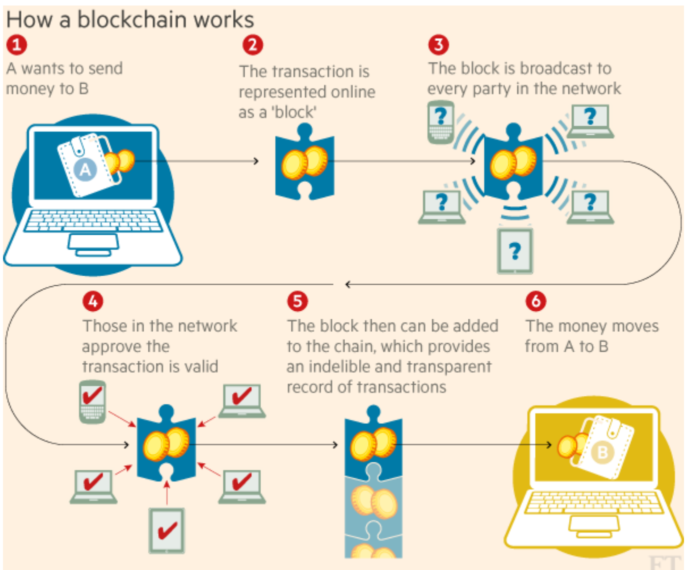
4.7 Blockchain BC

4.7.1 Framework



4.7.2 Technology Description

Blockchain is based on cryptography, a branch of mathematics. It is a decentralized shared digital ledger based on the consensus of a global peer network. The ledger is a series of encrypted "blocks" that are linked together in a public "chain". It is impossible to modify a block without the consensus of the whole peer network and this protects it from malicious attacks or data falsification. The figure explains how a blockchain works:



source: Sosa R., del Pino M. Entendiendo Blockchain. Revista de economia LoyolaEcon. 2019.

Blockchain is known as a trustless system since you do not need to trust specific participant in the transaction for the transaction to occur. It is intrinsically characterized by transparency and authentication. A specific and useful application of blockchain regards smart contracts which are essentially self-executing tasks that are coded through the blockchain and executed when a certain condition is met. It eliminates the need for administrative steps, cutting costs and reducing the error possibilities.

Blockchain plays a crucial role in revolutionizing the business approach from a classic ownership model to a usership model.

Moreover, blockchain facilitates the determination of the ecological footprint of diverse activities since it supports all the components identification throughout a product's lifecycle. It can also verify the provenience and the sustainability labels and certification of a product.

4.7.3 Technology applied to the Transport Sector

Blockchain enables cost-saving and more efficient business for transportation and logistics operators. It allows smart contract management, documentation and ensures trustworthy data across the involved ecosystem since the entire network contributes to data validation.

Blockchain and IoT can be combined offering huge benefits for the logistic; it is particularly used to monitor the condition of refrigerated shipments and perishable goods, to assure the provenience of specific food products and for order tracking and authentication. For example, IoT sensors can measure the volume in the cargo/ship/truck and share this information through the blockchain. It is particularly useful for the products which are paid in volume. Or even, IoT sensors can measure significant parameters, such as temperature, humidity which are crucial in pharmaceutical or food transports.

Blockchain plays a crucial role in transforming the historical approach of ownership toward a user-ship model, of mobility as a service. Mobility as a Service (MaaS) is based on providing users with information on the optimal route to reach the desired destination and suggesting multi-modal transportation services (possibly different from private cars). It usually offers other details such as the travel cost, required time, offering the chance of booking, buying tickets and validate them. Thanks to the blockchain it is possible to record users' data and share it anonymised to improve the service. They are shared in a distributed ledger of the blockchain among different transport operators, transaction processors and MaaS service providers, allowing the information exploitation, increasing reliability and transparency. Moreover, blockchain technology with smart contracts executed on edge (cf. CC - EC) can directly efficiently connect provider and travellers; specifically, the tickets and payment methods particularly can be programmed as smart contracts stored and verified in blockchain by different transportation providers.

Currently, central MaaS operators also have the role of intermediation between transportation providers and passengers. A blockchain-based MaaS can eliminate this intermediation, improving trust and transparency for all the involved stakeholders. Edge computing can support it since the power of computing and resources are distributed to different transportation providers at the edge of the network in a decentralized way.

Blockchain can also support the sharing of private vehicles, i.e., it allows the ownership of a single vehicle, shared among different users, with the property management entrusted to a platform.

Blockchain can also be applied for the traceability of the raw materials applied for electric cars' batteries. Some of these raw materials, such as cobalt, are an open sustainability issue and this technology can be useful to declare that the material supply has been conducted responsibly.

The last-mile problem is a logistic problem related to the deliveries. Usually, the last miles are very expensive and scarcely efficient compared to the whole trip. To address this problem, recently, drones have been suggested. The problem arises since deliveries involve many participants (e.g., sender, intermediary, receiver) who may not trust each other. So blockchain-based drone delivery can be a strategy to overcome the last mile problem in logistic.

Finally, storing and validating the V2V communication data on a blockchain can be very supportive for connected vehicles.

4.7.4 Impacts

Blockchain positively impacts logistic operations, since it:

- eliminates and speed up a high number of communications (a refrigerated shipment from Kenia to Rotterdam requires more than 200 communications)[8] and this reduces process and administration costs;
- reduces inefficiency and avoid the products' lost (especially in the pharmaceutical refrigeration chain which is subjected to severe controls);
- increase the alignment among all the different involved stakeholders (port, rail, road operators, customer, producers, etc.);
- support cargo/delivery vehicles traceability.

Blockchain also allows the spread of MaaS platforms: currently, centralised MaaS systems lack flexibility, trust and transparency (this also make International MaaS difficult to be realized). All these obstacles can be overcome thanks to blockchain. In this way, the need for separate MaaS operators, and extra commercial agreements among service provides and MaaS operators would be obsolete and service providers could connect their services for full journey in a peer-to-peer way.

[8] https://www.winnesota.com/blockchain

4.7.5 SWOT analysis

Strengths	Weaknesses
• increase information exchange reliability; • transparency and traceability; • reduce inefficiency and costs; • new business model for logistic as well as private mobility.	• require appropriate governance for it to operate; • need of highly specialized human resources; • high amount of energy needed for managing and operating it.
Opportunities	**Threats**
• fertile ground for shared mobility, inter and multi-modality solutions, Maas, coordinate traffic management, other smart city initiatives; • support electrical mobility (battery swapping authentication, sharing for energy and power capacity of batteries).	• business owners' reticence; • lack of overall consensus; • risk of corruption and money laundering activities; • standards in early stages of development, need for a higher standardization; • ethical and privacy concerns; • weak willingness of collaboration between public and private providers; • potentially exposed to cyber-attacks.

4.7.6 Application

Blockchain and MaaS - Netherlands
https://www.smartcitiesworld.net/news/news/blockchain-platform-developed-for-mobility-as-a-service--5239

Electric vehicles' battery traceability through blockchain
https://www.media.volvocars.com/it/it-it/media/pressreleases/260242/volvo-cars-ricorre-alla-tecnologia-blockchain-per-tracciare-il-cobalto-utilizzato-nelle-batterie-del

4.7.7 Tips/Requirements

Nowadays blockchain applications in the transport sector are quite limited, but it seems to be potentially really worthy for the sector.

4.7.8 Interactions with other technologies

Blockchain – Internet of Things: cf. IoT

Blockchain – Big Data Analytics and Artificial Intelligence: cf. BD – AI

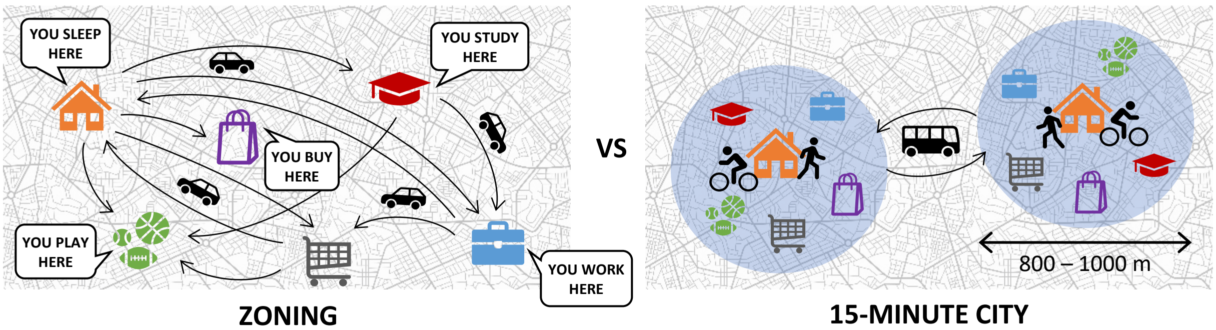
Blockchain – Cloud and Edge Computing: cf. CC - ED

5 Urban transformations and impacts

The mobility revolution related to the spread of AVs will not be only a technological transformation, but it is going to deeply alter the design of cities in the next future. In such a relevant change it is important to take the chance to adopt a human-focused approach again, keeping people at the centre of this transformation. It is important to remember that streets – and public space in general – should be for people and not for vehicles only, like it was before the wide spread of cars, and therefore a pleasant and comfortable environment and a perception of safety are essential.

If urban planners and designers will play a crucial role in the redevelopment of the layout of urban streets, urban design follows political decisions, so politicians and decision makers are going to choose which road users will be prioritized in each area of the city and in each street.

Mobility is deeply influenced by urban planning and a holistic approach must be adopted in city management. Urban layout can generate or solve traffic problems, therefore a change in city officials' mindset is needed and mobility must always be considered in the urban planning phase. Zoning, an approach which separates cities into strictly monofunctional areas (i.e., residential area, business district, education district, shopping area/shopping mall, sport/leisure area) and obliges people to move between them during the day, is still widespread and increases the lengths of daily commutes, supporting private motorized mobility and generating traffic congestion and large parking space need as a consequence. On the other hand, the 15-minute city is a new urban planning approach promoting the creation of vibrant multifunctional neighborhoods where people can find everything they need in their daily lives within a distance that is possible to reach on foot or by bike in a reasonable time (15 minutes). Adopting this new urban planning approach is possible to create a vibrant polycentric city in which people move mainly by active mobility modes within their neighborhood and use public transport or MaaS to move between different neighborhoods.



Moreover, such a city model implies other social changes: a more flexible work and educational model *(e.g. smart/remote working, e-learning or a mixed-modality)*, stronger communities and a dynamic and flexible real estate market with accessible housing for everyone and the possibility of moving easily following work or other needs.

The importance of urban mobility management

The shift from a traffic management approach to a mobility management one is needed and the Covid-19 pandemic kickstarted this process accelerating the transition of society towards digitalization. A mobility management approach acts on mobility demand and hours in order to avoid some travels or increase timetable flexibility and differentiation, reducing the impact of peak hours and traffic congestion consequently. This approach acts on the causes rather than trying to mitigate the consequences – like traffic management does - and the work model transformation with a wider adoption of smart or remote working helps. After the change in work habits due to Covid-19 pandemic mobility is related mainly to leisure for which active mobility and other sustainable alternative modes must be promoted.

New street use rules are needed

Since a people-centric city implies that the urban environment is safe, livable and comfortable, some road rules should be modified in order to prioritize people over motor vehicles.

There is no need to wait for the spread of AVs on city streets to modify some driving rules because they are already applicable and useful in order to enhance the quality and livability of urban environments. When AVs will be introduced the other road users will already be used to the new rules and road uses and new vehicles will only have to obey them like human drivers did.

Speed

A reduction in speed limit increases safety because low speed can avoid accidents involving the most vulnerable road users (i.e., pedestrians and micromobility users) and reduces fatalities considerably[9]. In addition, it reduces noise pollution increasing comfort and livability of urban spaces and contributes to the sustainable development as well.

The **Stockholm Declaration**[10] is the final outcome document of the **Third Global Ministerial Conference on Road Safety** (Stockholm, 19-20 February 2020), a meeting where Ministers and experts from 130 countries gathered to discuss how to improve global road safety in the next decade aiming at halving the number of road deaths by 2030. Resolution 11 mandates a maximum road travel speed limit of 30 km/h in areas where vulnerable road users and vehicles mix in a frequent and planned manner, noting that efforts to reduce speed will have a beneficial impact on air quality and climate change as well. Following the Declaration Spain reduced the speed limit to 30 km/h on all two-lane urban roads in November 2020 and the Dutch House of Representatives approved a plan to introduce a standard limit of 30 km/h in all built-up areas on the 27th of October 2020. Spain plans to go further imposing a 20 km/h speed limit on streets where roadway and pavement are not clearly separated, a very common situation in historic city centres.[11] In fact, in some critical areas where different road

[9] *"A pedestrian or cyclist being hit by a car at 50 km/h will lead to a fatality in 20% of cases, this falls to just 3% at 30 km/h; a near seven-fold reduction." Ceri Woolsgrove, European Cyclists' Federation Policy Officer* https://ecf.com/news-and-events/news/30-new-50-dutch-reduce-default-speed-limit-nation-wide

[10] https://www.roadsafetysweden.com/about-the-conference/stockholm-declaration/

[11] https://www.bloomberg.com/news/articles/2020-11-18/speed-limits-are-dropping-in-europe-and-the-u-k

users share the street space motor vehicles could be allowed to enter but their speed should be further limited to 20 or even 10 km/h.

Besides rules, speed reduction can be achieved through traffic calming measures and physical modification of streets (e.g., chicanes, raised pedestrian crossings at the level of the pavement, narrow lanes) and the shared space approach is one viable design strategy. Traffic calming measures will not be necessary anymore in the future since fully autonomous vehicles are programmed to follow the rules, anyway some physical elements could be useful to protect pedestrians in the case of autonomous driving failures.

Distance between moving vehicles
An increase in distances between moving vehicles make street crossing easier and safer for pedestrians. Nowadays heavy traffic on main urban streets make crossing dangerous and complicated since there is not enough time for pedestrians to cross a continuous flow of passing cars. Increasing distances, and so making the vehicular flow less continuous, pedestrians have more chances and time and vehicles can detect people crossing and reduce their speed in order to allow them to pass on the other side without stopping completely.

Shared responsibility
Pedestrians must be aware that, even if they have the priority and can be detected by AVs, the stopping distance remains the same; they cannot expect a vehicle to stop if they cross the road just in front of it suddenly. Consequently, Human-machine interaction will gain more importance as autonomous vehicles enter the urban scene in order to coordinate the movements of different road users.

Urban space management measures

Urban space is a scarce resource in dense city centers, therefore a proper management is essential in order to allow the best and more efficient space exploitation dealing with many – and constantly increasing - different conflicting legitimate interests. The e-commerce increased deliveries making city logistics faster and more complicated. Traffic flows of different mobility modes, activities and space use needs change in different seasons, days of the week and time of the day and for this reason the urban space optimization requires a responsive real-time data-driven approach. The **'Time of Day Management'** approach could allow this new urban space management model, exploiting **real-time data** gathered through sensors (installed both on-site in streets and on-board of vehicles) or other devices (e.g. smart cameras) and enabling a **flexible traffic and urban space use management**. In this way it is possible to assign a temporary purpose to some lanes (e.g., for delivery operations), close a street to ease walking or increase the number of lanes dedicated to bike circulation only during rush hours and re-routing traffic at the same time. A mobility management plan could prioritize different users during different times of the day: for example, city logistics early in the morning, commute (mainly by public transport, bike and on foot) during peak hours, delivery later in the morning and in the afternoon and events, leisure activities and outdoor dining in the evening and at night. Together with real time data, a database is useful in order to do simulations, create different scenarios and predict urban space possible uses. If a high pedestrian activity is recorded in an area at a certain time, speed limits could be reduced, some streets could be closed and vehicles could be re-routed automatically to avoid dangers and traffic congestion.

Different strategies for different urban street typologies

There are many different types of streets in the urban environment: they differ from each other according to the traffic intensity which impacts on their layout and space allocation and management. A foreseen next change in driving technology is a great chance to question the present model and the motor vehicle priority in city centers towards a more human-centered approach. There is no need to wait for the redevelopment of street layout and it is important to adopt the correct strategy for each street type.

Multiway boulevard

This kind of streets are large in section and present heavy traffic flows of different modes at high speed usually. They are the vital main circulation paths in the urban environment connecting different neighborhoods and allowing urban movements. Nowadays they are uncomfortable places for people and are perceived as unsafe due to heavy traffic and high speed. The best strategy in this case is reducing speed, separating spaces for different road users as much as possible and making crossing easier and safe for pedestrians. Separating lanes for public transport (e.g. BRT), private traffic and micromobility and creating flexible lanes, which can serve different purposes (e.g. extra lanes for circulation during rush hours, pick-up/drop-off spaces for passenger transportation services or operational stop spaces for delivery) in different days and moments of the day, on the curbside is a good strategy as well as providing frequent crossing points for pedestrians with protected traffic islands in the roadway.

Main public transport route

This type of street can be the same of the previous one: nowadays the main public transport routes run along the main urban streets where most of the vehicle traffic is. Reserving some lanes for public transport only can make it faster and the most convenient urban transport mode since delays related to private traffic congestion can be avoided. In a general urban regeneration plan some public transport corridors could be created reserving some whole streets for PT and reclaiming more space for pedestrians and micromobility users (on bike lanes), making them more vivid and livable.

Downtown street

This is the road type with the highest space use demand and conflicts, since most of the activities are concentrated in city centres (e.g. shops, offices, hotels, restaurants, etc.), and streets should be meeting spaces as well and not only vehicle circulation network elements or parking spaces. In these streets social uses should be prioritized, so a strategy aiming at reducing considerably accessibility of private vehicles and speed *(30 km/h)* and eliminating on-street parking could be deployed adopting a shared space approach with pedestrian priority.

Neighborhood main street

These are lively streets with features similar to downtown streets, but at a smaller scale. They are important local circulation system elements, often connected to main urban roads linking different neighborhoods. Slow speed could allow motor vehicles and micromobility to share the roadway or different road surfaces can indicate different spaces for different road users.

Residential street

Nowadays these streets are dedicated to local traffic and parking mainly. Traffic flows are low, so they could be transformed in residential front yards serving as meeting places. Pedestrians are to be prioritized and motor vehicles could be allowed proceeding at walking pace only. Thanks to low traffic and speed there is no need for space segregation and a shared space approach can be adopted in the street layout design.

Some could object that these measures are not suitable for historic city centres because there is not enough space into the existing built environment, but this vision is connected to a traffic management mindset. Nowadays the traffic management practice aims at making motor vehicle traffic as fluid as possible, trying to allow as many low occupancy rate private vehicles to pass through existing narrow road sections in the least time possible. This vision reflects and supports the most widespread current modal split in developed countries which is not sustainable, not only from an environmental point of view but also from an urban road space use one: there is a maximum number of vehicles which can pass through a given urban street section at a speed that does not impact on safety and livability of an urban environment. If we shift to a mobility management approach, we will not build urban roads with more lanes and higher speed limits, but we will define the maximum capacity for each street and then act on the modal split to meet the existing urban street network requirements. Some tools to induce a change in the modal split are private traffic restrictions and congestion charge and the decision is up to policy makers once more.

The next section provides some factsheets focusing on the main basic urban elements that are foreseen to be impacted by the introduction of AVs. As discuss previously, in some cases this transformation could adopt a shared space approach, therefore a quick overview on shared space and its main applications and design principles is presented as well with some examples of existing places in different countries in the world. To conclude, some visions on possible design strategies and layouts of future urban spaces are shown presenting the results of an architecture competition.

5.1 Curbside

Functional system: Passenger transportation / Freight delivery / Parking

Road users involved:
- Vehicles

Element functional requirements:
- allowing vehicle stops outside the main circulation lanes in order to respond to different needs:
  - boarding and alighting of passengers *(e.g. public transport stops, taxi stations)*
  - freight delivery *(e.g. operational stops spaces)*
  - parking

Goals:
- respond to different needs of stopping the vehicle (both short and long term) without blocking the traffic circulation

5.1.1 Future transformation:

Preliminary assumptions:
- public space in urban areas is limited and therefore it is a valuable resource – especially in dense city centres – since it serves many different functions and needs
- Nowadays private vehicles are parked for over 90% of time occupying large areas of curbside in cities, but shared autonomous vehicles in the future will have a much higher use rate, minimizing idle periods

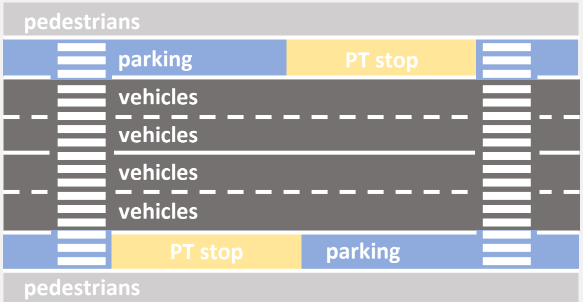
Strategies:
- **flexible management of curbside space** thanks to real time data gathered through on-site sensors, data analytics, Artificial Intelligence - Computer Vision, simulation, prediction and optimization

Actions:
- **redesign the general street layout reducing the space dedicated to the circulation of vehicles** *(number and width of lanes)*
- **adopt a 'Time of Day' management approach**, assigning different functions to road spaces according to different days, time of day and traffic conditions
- **consider the different curbside use needs and prioritize the functions that benefits collectivity the most**
- **set up a policy and rule curbside space usage** *(e.g. permissions, pricing, etc.)*

Please note: the main future changes involving curbside will be management measures rather than physical transformations.

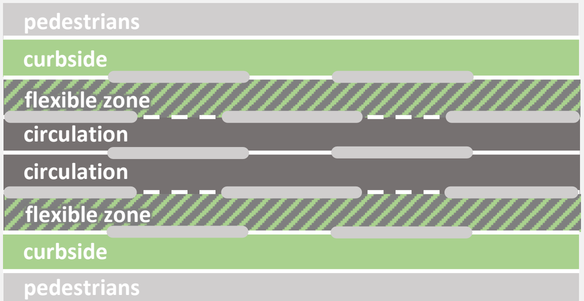
Concept diagram:

TODAY



Nowadays the different parts of the roadway are strictly assigned to specific functions permanently over time. There are two principal zones: the curbside and the part dedicated to vehicle circulation. The curbside, despite a lot of different functions would require it, is mainly dedicated to parking, public transport stops and freight delivery operational stops and only vehicles use it.

IN THE FUTURE



A flexible management of the street would allow much more different functions and road users to exploit the available space, making the public realm more vibrant and liveable. The spread of shared AVs in a MaaS model will reduce parking space need and the curbside will be more available for different functions like sharing mobility stations, parklets, pocket gardens and green infrastructure, dehors, kiosks and street food facilities. A 'Time of day' management together with real-time data will allow the change of space functions during the day: during rush hours more space could be reserved to passenger transportation and circulation reducing spaces for freight delivery. Flexible zones or lanes could have different purposes in different times of the day: extra lanes for circulation during rush hours, bike lane, pavement extension, pick-up/drop-off, delivery operational stop space, etc..

Urban design features:

the street space must be as free as possible with flat surfaces in order to allow a flexible use. Nonetheless spaces must be clearly identified for safety reasons: it must be clear to ever road user which part of the street is mainly dedicated to circulation, which is the pavement, the bike lane, the curbside or the flexible space. With AVs wide adoption traffic calming elements will not be necessary anymore, but urban furniture could be useful to protect pedestrians and cyclists in case of AVs faults.

New technologies adoption:

DSRC (V2I / I2V) and V2N communication; IoT - Internet of Things; Big Data Analytics; Artificial Intelligence: Computer Vision (Object Detection and Action Recognition); Simulation and Optimization based on data collection (city digital twin and traffic model).

Hardware and sensors:

Radio-Frequency modules (transceivers); Cameras; LIDAR; Variable-Message Signs (VMS).

Transformation advantages:

- much more road users *(not only vehicles)* will benefit from the use of curbisde and flexible zones
- more fair use of public space *(which is a valuable resource)*
- citizens can find a much wider range of functions and amenities within a shorter distance
- increase in operations efficiency (both in passenger transportation and in freight delivery)

Transformation weaknesses or potential threats:

- the transformation could turn into a chaos if the space is not managed properly and in an effective way: city officials must supervise the use of the streets and the observance of rules by all road users

Urban impacts:

- more space becomes available for functions and activities other than vehicle circulation (*e.g. parklets, seating, kiosks, etc.*)
- urban streets become again more liveable for people, making city centres - and public space in general - livelier
  - a more pleasant public space attracts people and support economic activities (*e.g. shops, restaurants, cafes, etc.*)

5.2 Intersection

Functional system: Circulation

Road users involved:
- All

Element functional requirements:
- Allowing all road users to pass through a point where different flows with different directions converge heading to their final destinations since it is a node of the road network where the spaces of two or more streets overlap generating many conflict points *(both between different vehicles and between vehicles and other road users)*

Goals:
- Regulating the movement of all road users with collision trajectories in order to provide circulation safety

5.2.1 Future transformation:

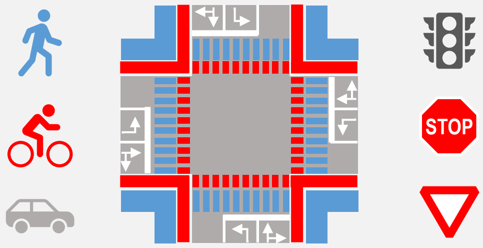
Preliminary assumptions:
- since the shift to a fully autonomous transport system will not be immediate, **two future scenarios should be foreseen:** at first both human driven vehicles and AVs will share the road space (**intermediate phase scenario**) but in the end it is very probable that all vehicles will be autonomous gradually (**final transformation scenario**)
- in such a complex system, besides rules, technology reliability and communication between different categories of agents are essential for the proper functioning: in particular, vehicles must be able to recognize other road users *(without imposing pedestrians to be equipped with special devices or sensors)* and coordinate movements through human-machine interface systems *(on-board of vehicles or on site)*

Strategies:
- **managing vehicle circulation through communication prioritizing people who are the most vulnerable road users**

Actions:
- **separate different flows** (vehicles, micromoblity and pedestrians) **as much as possible and clearly define separate spaces at intersections**

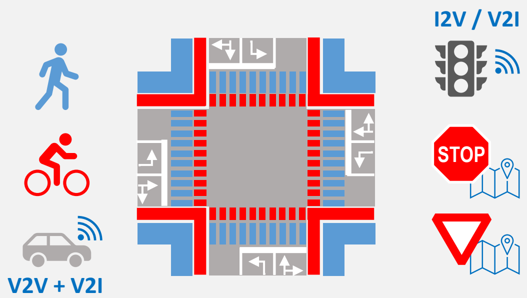
Warnings: people behaviors *(both as pedestrians and vehicle drivers)* **are unpredictable and** – differently from programmed machines – **could be the consequence of decision-making mistakes or could even not obey to the given rules, so they represent a dangerous exogenous variable in an automated system.**

Concept diagram:
TODAY



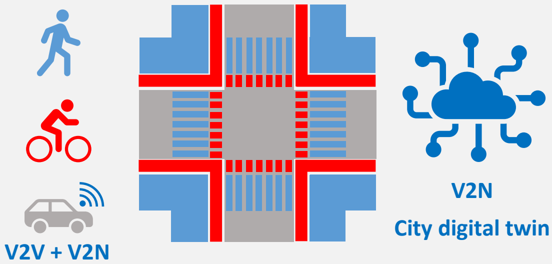
Nowadays traffic at intersections can be regulated through traffic lights or stop or priority logics. This approach often is not adaptive to variations in traffic flows along different direction in different days and moments of the day and negatively affects traffic fluidity and travel times. Another option is the realization of a roundabout.

IN THE FUTURE
Intermediate phase scenario *(mixed traffic: human driven vehicles + AVs)*



All vehicles are equipped with V2V and V2I communication systems that allow to coordinate their movements through the intersection, providing information to ADAS systems (assisting human drivers) and AVs in their tasks of speed evaluation and route prediction of other vehicles. Fully autonomous vehicles could need no traffic signals on site because they could rely on digital maps and communication systems; human drivers on the other hand need a communication interface which could be physical on site (traffic signals and smart traffic lights communicating with vehicles) or digital on board (communication dashboard and ADAS providing traffic signal information to the driver).

Final transformation scenario *(fully autonomous transportation system scenario)*



People – both pedestrian and micromobility users – have priority over motor vehicles in the urban environment. AVs reduce their speed approaching intersections in order to detect the presence of other road users and guarantee the maximum safety in such a critical point. AVs route planning and traffic are managed through a centralized management system (city digital twin) and vehicles are controlled through V2N.

Urban design features:
more narrow lanes allow larger spaces for pedestrians and micromobility users in the streets.

New technologies adoption:
DSRC (V2V and V2I / I2V) and V2N communication; IoT – Internet of Things; Edge Computing; Big Data Analytics; Artificial Intelligence: Computer Vision (Object Detection and Action Recognition); Simulation and Optimization based on data collection (city digital twin and traffic model).

Hardware and sensors:
Radio-Frequency modules (transceivers); Cameras; LIDAR; HMI - Human-Machine Interface (on-site Variable-Message Signs/on-board dashboards).

Transformation advantages:

- speed reduction makes urban space more pleasant and liveable besides increasing safety
- pedestrian and micromobility flows become more fluid since they have priority over motor vehicles and so the more sustainable modes are the most convenient and time-saving as well

Transformation weaknesses or potential threats:

- if the vehicle speed decreases approaching intersections and many AVs travel in rush hours together with pedestrians, micromobility users and cyclists, localized gridlocks or even congestion of the whole road network could arise caused by intersections where vehicles must prioritize the other more vulnerable road users whose flow could be intense and continuous

Urban impacts:

- urban streets become safer and more liveable for people, making city centres livelier
  - a more pleasant public space attracts people and support economic activities (*e.g. shops, restaurants, cafes, etc.*)

5.3 Parking facilities

Functional system: Parking

Road users involved:
- Vehicles

Element functional requirements:
- allowing long term stops of vehicles not in use outside the street

Goals:
- concentrate many vehicles in the smallest possible space next to urban traffic attractors or points of interest (services, shopping or business districts, etc.) without interfering with traffic

5.3.1 Future transformation:

Preliminary assumptions:
- Nowadays private vehicles are parked for over 90% of time occupying large parking areas in cities, but shared autonomous vehicles in the future will have a much higher use rate, minimizing idle periods
- A shared AV MaaS system will require less vehicles than today private ones to transport the same number of people thanks to optimization
- Future Connected Autonomous Vehicles (CAVs) will be electric (CAEVs)
- Future CAVs will be able to self-manage parking space minimizing it as much as possible

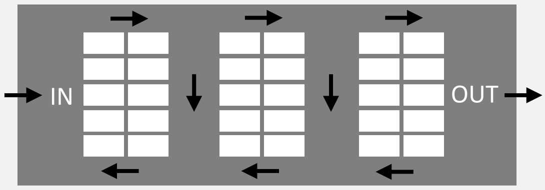
Strategies:
- **Promote a MaaS system which aggregates rides asking the passengers to reach a pick up point within a walkable distance** in order to avoid the potential exponential increase of traffic volumes and vehicle travelled distance associated with the mass adoption of AVs *(in a scenario in which AVs are private or go to pick up passengers wherever they are located)*

Actions:
- **Remove parking from streets concentrating vehicles in already existing parking facilities or creating new ones**
- Dedicate curbside space only to short term stops for passenger pick up and drop off, prioritizing its use for higher social and economic value functions
- **Make parking facilities multifunctional**: a vehicle storage can be a **charging hub** and serve as **energy storage for the electric grid** as well thanks to V2G or battery swap technologies

<u>Please note</u>: the future MaaS system setup and city management will be essential

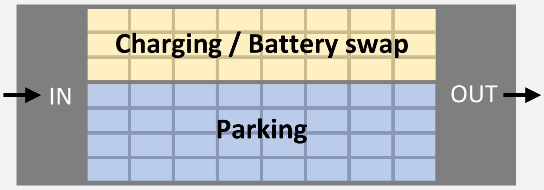
Concept diagram:

TODAY



Parking facilities require circulation lanes that allow direct access to every single parking lot, resulting in a very large space need.

IN THE FUTURE



A MaaS system based on AVs will reduce the space needed to park large fleets since less circulation lanes would be necessary or they would not be necessary at all.

Urban design features:

In a MaaS system operated with AVs the parking facility *(or fleet storage)* does not need circulation lanes since there is no need for direct access to every single vehicle, but - like in taxi stations – the first vehicle in the row leaves to pick up the passenger who requested the mobility service. This layout allows to store more vehicles maximizing the use of available space: the diagrams in the previous section show that is almost possible to double the number of vehicles stored in the same space *(56 vehicles versus 30 vehicles with a traditional layout)*. Moreover, one part of the fleet storage space could be equipped with battery swapping stations or *(inductive)* charging spaces depending on the charging system chosen.

New technologies adoption:

DSRC: V2I / I2V communication; IoT – Internet of Things; Big Data Analytics; Artificial Intelligence: Computer Vision (Object Detection and Action Recognition); Simulation and Optimization; Blockchain.

Hardware and sensors:

Radio-Frequency modules (transceivers); Cameras; wireless parking lot occupancy sensors; LIDAR.

Transformation advantages:

- urban streets could be free from parked vehicles and provide more space for people and leisure, social or economic activities

Urban impacts:

- a large amount of space *(not only curbside but also entire city squares in some cases)* becomes available for functions and activities other than parking (*e.g. gardens, playgrounds, seating, kiosks, etc.*)
- urban space becomes again more liveable for people, making city centres - and public space in general - livelier
  - a more pleasant public space attracts people and support economic activities (*e.g. shops, restaurants, cafes, etc.*), both indoor and outdoor (*i.e. dehors*)

External links:

- Minimizing Parking Area in Automated Parking Systems: https://www.youtube.com/watch?v=pCzI-l8tsPY

5.4 Pedestrian crossing

Functional system: Circulation

Road users involved:
- Pedestrians
- Vehicles

Element functional requirements:
- allowing vehicles to detect pedestrians intending to cross the road
- allowing pedestrians to cross the space of the road dedicated to the vehicle circulation (*roadway*)

Goals:
- increasing pedestrian safety in such a conflict point

5.4.1 Future transformation:

Preliminary assumptions:
- pedestrian priority in urban areas
- vehicle speed limit reduction in urban areas *(30 km/h)*
- increase in the distance between vehicles travelling in urban areas

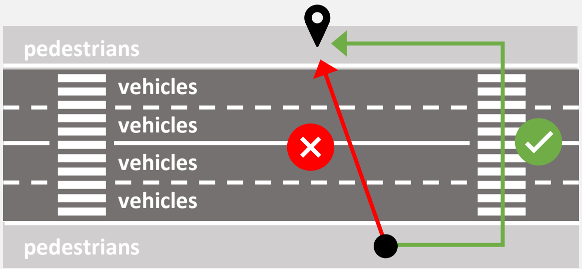
Strategies:
- **reducing the space dedicated to the circulation of vehicles** *(number and width of lanes)*
  - reduction of the pedestrian exposure zone consequently

Actions:
Two alternative approaches can be adopted:
a) creation of more frequent pedestrian crossing points (*spacing 15-30 metres*)

b) allowing crossing everywhere along the street:
- creation of safe spaces for pedestrians during crossing (*medians and traffic islands*).

Concept diagram:

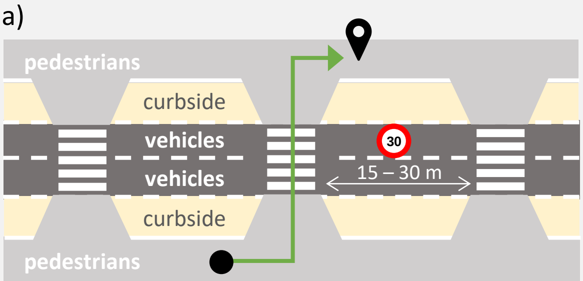
TODAY



Nowadays the larger section of urban streets is dedicated to vehicles' circulation. Pedestrians can cross only at regular crossing points, often resulting in higher distance walked and delays in reaching the destination. Heavy traffic can make crossing difficult and often the exposure zone is wide due to the large number of lanes of the roadway and their width.

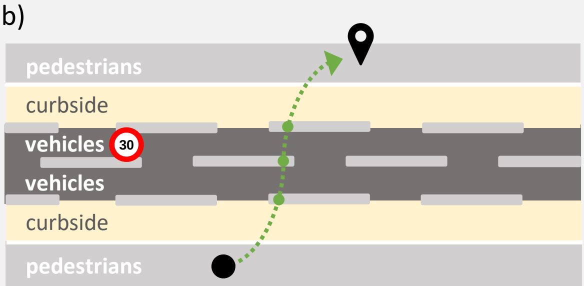
IN THE FUTURE

a)



The reduction of the space dedicated to vehicle circulation (less and more narrow lanes) results in a shorter exposure zone for pedestrians. The creation of more frequent pedestrian crossings together with the reduction of speed and the increase of distance between in-motion vehicles make crossing easier and safer.

b)



A more dynamic street space allocation, with flexible use of curbside space according to traffic volume, together with the creation of pedestrian safe spaces between lanes (medians or traffic islands), speed reduction and increase of distance between in-motion vehicles make the street more pedestrian friendly and accessible for everyone.

Urban design features:

With AVs wide adoption traffic calming elements will not be necessary anymore. If pedestrians are prioritized the street surface should be flat without level separation between pavement and roadway. Urban furniture could be used to separate different spaces and protect pedestrians and cyclists in case of AVs faults.

New technologies adoption:

DSRC: V2I / I2V communication; Edge Computing; Big Data Analytics; Artificial Intelligence: Computer Vision (Object Detection and Action Recognition); Simulation and Optimization based on data collection (city digital twin and traffic model).

hardware and sensors:

Radio-Frequency modules (transceivers); Cameras; LIDAR.

Transformation advantages:

- pedestrians reduce distance walked and spend less time to reach their destinations
  - walking becomes the most convenient mode in terms of time spent for urban movements
- **inclusive design**: potential **increase in accessibility of public space** thanks to the elimination of level separations *(e.g. wheelchair accessibility)*

Transformation weaknesses or potential threats:

- since pedestrians and vehicles share the same space, vehicles must prioritize pedestrians and be very reliable in their autonomous driving task

Urban impacts:

- more space becomes available for functions and activities other than vehicle circulation (*e.g. parklets, seating, kiosks, etc.*)
- urban streets become again more liveable for people, making city centres - and public space in general - livelier
  - a more pleasant public space attracts people and support economic activities (*e.g. shops, restaurants, cafes, etc.*)

5.5 Shared space

The shared space urban design approach minimizes the segregation between different road users. This strategy relies on the assumption that the sense of uncertainty generated by the lack of curbs, road surface markings, traffic signs, and traffic lights induces drivers to reduce speed and to pay more attention to other road users. This urban design approach is believed to reduce the dominance of vehicles on the street, road casualty rates and increase safety, but it is not particularly suitable for blind, partially sighted and deaf people who lack traditional reference points and feel more comfortable and safer where there is a clear separation of road spaces. The proper functioning of such a scheme is based on human interactions and not all the implementations have been successful.

There are different types of streets in the urban environment and this design approach is not applicable to multiway boulevards, main public transport routes and neighborhood main streets where the vehicle traffic is heavy, but could be applied in low traffic volume downtown and residential streets. Shared space could be a good solution for streets with high levels of pedestrian traffic, but motor vehicle traffic flows must be below 90 vehicles per hour (no more than 1 vehicle passing each 40 seconds on average) and speed not above 30 km/h.

The introduction of AVs could contribute to a wider adoption of the shared space design approach: residential and downtown streets could have a flat surface with different colors or materials indicating the lanes for AVs circulation while people could use all the space since they have priority. The separation between AVs lanes and the other road spaces could be made with urban furniture (e.g. benches or planters) or green spaces (e.g. flowerbeds or tree rows). Moreover, keeping a space reserved for pedestrians only (pavement), some traditional pedestrian crossings and tactile paving, accessibility would be increased for everybody.

source: https://en.wikipedia.org/wiki/Shared_space#/media/File:New_Road,_Brighton_-_shared_space.jpg

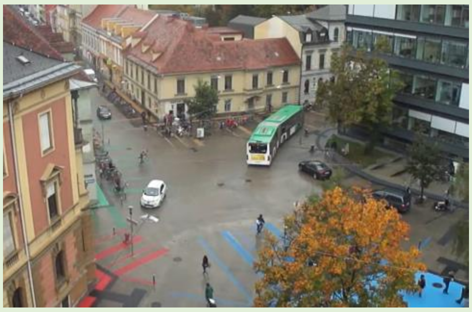
Examples in the world:

Hargreaves Street, Bendigo, (AU-VIC)

source: bendigoadvertiser.com.au

Street view External link

Sonnenfelsplatz, Graz (AT)



source: https://www.youtube.com/watch?v=4yR8ifKNOu4

Street view Video

Drachten (NL)

source: https://worksthatwork.com/1/shared-space

Street view Video

Auckland (NZ)

source: Google Street View (Elliott Street)

Street view 1
Street view 2 Video

Skvallertorget square, Norrköping (SE)

source: https://www.youtube.com/watch?v=pKzhatsLgAY

Street view Video

Exhibition Road, London (UK)

source: https://www.geograph.org.uk/photo/5787981

Street view Video

5.5.1 Variations of the shared space concept

Woonerf

Country of origin: Netherlands
Year of first adoption: 1976
Diffusion: Austria, Denmark, France *(zone de rencontre)*, Germany *(Verkehrsberuhigter Bereich)*, Israel, Italy, North America, Sweden, Switzerland *(Begegnunzone)* and United Kingdom *(see **living street**)*

A woonerf is a street where pedestrians and cyclists have the priority over motor vehicles whose speed is limited by traffic calming measures.
The city of Emmen was designed following the concept of woonerf in the 1970s and nowadays approximately 2 million people live in woonerf areas in the Netherlands.

source: https://commons.wikimedia.org/wiki/File:Gdynia_Abrahama_woonerf.jpg

Rules:

- Pedestrians have priority always *(children can play in the street)*
- Motor vehicles are allowed to enter woonerf areas but must proceed at a walking pace *(article 44 of the Dutch traffic code)* yielding to pedestrians
- Parking is allowed only in dedicated areas *(clearly marked by traffic signs)*

Urban design features:

- Traffic calming elements
- Green areas
- Absence of curbs: the pedestrian only area/pavement *(if present)* is at the same level of the roadway

Play street and home zone

Country: United Kingdom
Year of first adoption:
- play street: 1938 *(Street Playground Act)* – 1960 *(Road Traffic Act 1960 - section 49)*
- home zones: 2000 *(Transport Act 2000 – section 268)*

Play streets were created to allow street games and social interaction, contrasting through traffic and the invasion of parked cars in residential areas. Traffic safety was not the main goal of the institution of such kind of streets. The implementation of a play street requires the local community involvement: local traffic authorities consult residents on the precise uses allowed on each street and on the traffic speed, both reported in the 'Use Order' and 'Speed Order'.
A residential area with many play streets can be defined as a home zone and usually its boundaries are clearly defined visually through gates/portals or traffic signs.

Staiths South Bank, Gateshade (UK) – *source: Google Street View*

Rules:
- Pedestrians, children playing, cyclists and drivers have the same right to use the street
- Low speed: maximum vehicle speed is defined in the *Speed Order* of each play street/home zone *(approximately 20 km/h on average)*
- Regulated on-street parking *(in marked spaces only)*

Urban design features:
- Vehicles, cyclists and pedestrians share the road space, but sometimes a protected pedestrian path is present in order to meet visually impaired people needs
- Street furniture *(e.g. benches, tables)*
- Playgrounds
- Traffic calming measures integrated into the road design and not introduced afterwards *(e.g. winding vehicle route and roadway narrowings to induce speed reduction)*
- Plants and green areas *(ideally maintained by residents)*

Living street

Country: United States of America

The living street concept was developed in the U.S. basing on the European shared space theories and experiences. Besides the traffic control and the increase of road users' safety, social, environmental, comfort, wellbeing and health aspects are central in living streets design. The living street relies on 3 street concepts:

- *Green streets: planters and bioswales are used to collect and filter stormwater protecting local water sources and, at the same time, plants sequestrate carbon dioxide and improve air quality*
- *Cool streets: plants (through evaporative cooling) and light-color materials of surfaces decrease the Urban Heat Island (UHI) effect reducing heat-related illnesses and increasing comfort and wellbeing of people*
- *Complete streets: accessibility, social equity and promotion of active mobility introducing street amenities (e.g. flowerbeds, seatings and trees) as well*

Bell Street, Belltown, Seattle (WA) - source: http://www.svrdesign.com/bellstreetpark/2014/7/2/2wkcrcabk59rntklpaz7bxlcjwsy9p

Rules:

- Similar to the rules of woonerf *(pedestrian and cycling priority, vehicle speed limitation and parking restrictions)*

Urban design features:

Prerequisite: Living street implementations work in vibrant dense mixed-used neighborhoods: short distances promote active mobility *(up to 1 km walking and 3 km cycling)* and density makes public transport efficient and economically sustainable. Design quality is essential to attract people.

- Traffic calming measures *(e.g. narrow lanes, chicanes, diverters)*
- Adequate lighting at night
- Permeable paving
- Light-color materials
- Sun-shading elements *(e.g. tree rows, pergolas or porticos)*
- Green areas *(e.g. flowerbeds, planters, bioswales)*

External links:

https://www.healthebay.org/sites/default/files/pdf/fact-sheets/final%20living_streets_Guide_final-011916.pdf

https://www.denvergov.org/content/dam/denvergov/Portals/646/documents/planning/living_streets_initiative/LSI_12_3_2014_Planning_Board.pdf

Shared zone

Country: Australia and New Zealand

Shared zones are the implementation of the living street concept in Australia and New Zealand.

Greville Street, Prahran (AU-VIC) - *source: Google Street View*

Rules:

- Start and end of a shared zone is clearly indicated by specific traffic signals
- Motor vehicles and bikes must give way to pedestrians always
- Speed limit: 10 km/h

Urban design features:

- Change in road surface/color
- Lack of separation between pedestrians and vehicles
- Minimization of road markings
- Clear definition of parking bays
- Street furniture (e.g. seatings, planters, bike racks) can be use to protect a pedestrian only area
- Trees, plants, flowerbeds

5.6 Visions and projects on city street transformation

5.6.1 Driverless Future Challenge

Location: New York (US)

Status: design competition

Year: 2017

The Driverless Future Challenge is a competition launched by the architecture on-line platform Blank Space[12] *to reimagine city streets together with New York City. Participants have been asked to imagine how the AV spread would transform the urban space in New York City and its impact intersections, pavement, on new roadway uses and parking solutions. The aim of the competition was not providing only visions but concrete solutions: competition organizers and their partners want to help the winners to further develop their proposal and turn it into real companies and products to get cities ready for AV introduction in the future.*

External link: http://driverlessfuture.blankspaceproject.com/

Public Square *(winner entry)*

Authors: FXFOWLE with Sam Schwartz Engineering

source: http://www.fxcollaborative.com/projects/186/public-square/

[12] https://blankspaceproject.com/

The proposal is based on the consideration that nowadays vehicles in cities are parked for most of the time and provides a flexible, incremental, long-term vision on how to reclaim space for pedestrians. The Public Square project proposes a modular approach based on a squared grid made of infrastructure for power, water, Wi-Fi and smart street technology allowing different uses of each space over time. The project proposes eight square feet plug-and-play modules (e.g. green space, sharing mobility station, kiosk, playground, micromobility lane) that combined together can generate a great variety of different spaces. This project allows the streets to change easily as city needs change and one of the strengths of this proposal is claimed to be the installation ease.

source: https://vimeo.com/222721632

source: http://www.fxcollaborative.com/projects/186/public-square/

source: http://www.fxcollaborative.com/projects/186/public-square/

Video: https://vimeo.com/222721632

External link: http://www.fxcollaborative.com/projects/186/public-square/

6 Conclusions

At the conclusion of this report, it is evident that there are several areas of convergence across various business, but there are also notable differences in the approach to CAVs that vary from country to country.

We identified some main topics that have emerged as crucial issues on the impacts of CAVs planning.

- Safety and security are a must: expectations are high, but with so many advancements already in the works, changes seem to be on the way.
- Fleet management is now driving the improvement: the chance to manage fleets from a centralized control room offers great opportunities for urban transport optimization and urban mobility services.
- MaaS ecosystem: the arise and combination of new ICT technologies and business models gives the possibility of providing new, efficient and economically sustainable mobility services (even on demand) and integrating them into the existent transport system.
- Self-driving trucks are on the way: freight has a lot to gain in terms of productivity, and it has widespread industry support.
- Traffic is a dilemma: while everyone wants less congestion, and accessibility will play a key role, user behaviour and TNC strategy may mean more at first.
- A variety of last-mile solutions: there are several options in the mix, each bridging various requirements and geographic gaps.
- Limited vs. generalized implementation: where and why we see initial AV services cannot always correspond to where mass impact occurs.
- Deeper cooperation would be required: a key enabler is the transition from collaborations to long-term multi-party cooperation.
- Standards aren't always necessary: in the case of AV, comprehensive global and regional standards may not be required - rather, market interests will drive the evolution of standards.
- Policy makers are shaping deployment: businesses are attracted to proactive regulation, but the combination between light vs. heavy approaches can have an effect.

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See also the external links and the bibliographical references given in the factsheets of the previous chapters.

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