# THE FUTURE OF INTELLIGENT TRANSPORT SYSTEMS

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# Introduction

The term Intelligent Transport Systems (ITS) was coined several years ago, reflecting the continuously modernized manner in which people, vehicles, and other objects of the transportation infrastructure move and communicate. Especially with the enormous advances and incorporation of Information and Communication Technologies (ICT), ITS has become the cornerstone of transport and attracts immense research interest from the academia, resulting in innovative technological developments from the industry.

This book falls exactly in the realm of the above-mentioned grounds, containing a holistic approach on the latest technological advances that transform transport systems of all kinds and shape the way people travel around.

The contents of the book revolve around a set of pillars, namely:

1. technology enablers;
2. users;
3. business models;
4. regulation, policies, and standards; and
5. the future of ITS.

Overall, the book covers, in a holistic manner, aspects that are relevant to the next generation of ITSs in one place. The presentation of the book will follow the figure above in five parts.

Part 1 introduces the reader to all the technological enablers for building ITS. It provides a holistic approach to intelligent transportation. In particular, it will cover (a) the sensing technologies that can be used for data collection, (b) the wireless communication advances that enable fast data transfer, and (c) the computational technologies such as cloud and edge computing that allow flexibility and push applications, data and computing services to the logical extremes of a network. Last, this part will also provide information on connected vehicles and the available relevant test beds.

Part 2 of the book covers all aspects that are relevant to the users, as part of the transportation chain. It explores the needs, preferences, and identifies changes in travel decisions and technology acceptance.

Part 3 of the book focuses on the business and revenue models that influence ITS. In particular, it discusses on the design and pricing of ITS related services, the financing and revenue allocation models, the legal requirements and the user (driver/passenger) rights, defines the value chain, investigated the financing schemes for new ITS concepts, and investigates revenue allocation models.

Part 4 will investigate all policies that affect ITS, as well as proposing new methods to model ITS processes, so as to end up with new appropriate policies for promoting technological advances, rather than hindering them.

The last part of the book focuses on ITS applications, which are present in two different perspectives: (1) from the point of the transportation network and the applications that can improve network safety, traffic flow, and also on smart cities and urban mobility concepts, (2) from the vehicle point, with emphasis on autonomous driving. Emergency vehicle notification systems, variable speed limits, dynamic traffic light sequence, collision avoidance systems are some of the applications that will be presented in detail. Concerning autonomous driving, the various levels of autonomy, starting from the "eyes off" level and moving to the "driver off" case will be presented. All existing technology enablers for each level will be covered and the maturity of each solution will be described. User acceptance and ethics issues will be presented in detail in order to assist researchers, students, and practitioners to better design their solutions in the future in order to achieve wider acceptance.

As such, the book is a unique resource where the reader can turn to study EVERYTHING about ITS that is related to the future of mobility, combining personalized mobility, big data, and autonomous driving.

# Part I

# ITS technology enablers

Chapter 1

# Sensing and perception systems for ITS

## 1.1 Introduction: highly automated vehicles and the importance of perception

The ever-increasing utilization of vehicles along with the ongoing immense research in novel vehicular concepts has brought about the concept of highly automated and autonomous vehicles. The automation of vehicles—ultimately aiming at fully autonomous driving—has been identified as one major enabler to master the Grand Societal Challenges "Individual Mobility" and "Energy Efficiency". Highly automated driving functions (ADF) are one major step to be taken. One of the major challenges to successfully realizing highly automated driving is the step from SAE Level 2 (partial automation) to SAE Levels 3 (conditional automation), and above. At Level 3, the driver remains available as a fallback option in the event of a failure in the automation chain, or if the ADF reaches its operational boundaries. At higher levels (4 and 5), the driver cannot be relied upon to intervene in a timely and appropriate manner, and consequently, the automation must be capable of handling safety-critical situations on its own. This is shown in Table 1.1.

The automation of vehicles is strongly linked to their interconnection (V2V communications), as well as to their connection to the transportation (and also telecommunication) infrastructure (V2I), as those kinds of communications can pave the way for the design and delivery of innovative services and applications supporting the driver and the passengers (cooperative, connected automated mobility—CCAM). Despite the numerous advances in several initiatives related to CCAM, there are still plenty of limitations to be overcome, especially in the following areas:

1. Deployment cost reduction: At this time, CCAM solutions are associated with high costs that are associated with the distribution of the necessary infrastructure for their deployment.
2. Communication availability improvement for CCAM: Availability of state-of-the-art communication infrastructure/technologies nation-wide.
3. Vehicle cooperation improvement: In-vehicle intelligence, connectivity, and coordination among heterogeneous technologies.

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**TABLE 1.1 Summary of levels of driving automation for on-road vehicles.**

| SAE level | Name | Steering and acceleration | Perception | Fallback | System capabilities |
|---|---|---|---|---|---|
| **Human in charge of perception** | | | | | |
| 0 | No automation | Driver | Driver | Driver | None |
| 1 | Driver assistance | Driver + System | Driver | Driver | Some driving modes |
| 2 | Partial automation | System | Driver | Driver | Some driving modes |
| **System full in charge of perception** | | | | | |
| 3 | Conditional Automation | System | System | Driver | Some driving modes |
| 4 | High Automation | System | System | System | Some driving modes |
| 5 | Full Automation | System | System | System | All driving modes |

Source: ERTRAC, 2015.

4. Driving safety improvement: CCAM solutions that will assist the driver in effectively handling sudden or unforeseen situations, especially for SAE Levels 3 and beyond.
5. Business models: Solutions that will envisage new revenue generators for all involved stakeholders, that is, vehicle-to-business communications.
6. Traveler's information enhancement: Real-time, accurate, and tailored information provision to the driver, especially when information originates from multiple sources and is associated with large amounts of data.

Last, while many prototypes exist, which demonstrate CCAM technologies, they are confined to special applications and somehow limited to simple scenarios. Past and on-going projects on CCAM focus on vehicle platooning, where vehicles operate in a well-defined and structured environment (highway scenarios).

In such a context, the vehicle needs to efficiently (in a fail-operational manner) perceive its environment, that is acquire contextual information, so as to be fully aware of its surroundings and be able to take optimal decisions regarding its velocity, direction, and overall behavior on the road.

Any mobile robot must be able to localize itself, perceive its environment, make decisions in response to those perceptions, and control actuators to move about (Burgard et al., 1999). In many ways, autonomous cars are no different. Thus many ideas from mobile robotics generally are directly applicable to highly automated (also autonomous) driving. Examples include GPS/IMU fusion with Kalman filters (Thrun, Burgard, & Fox, 2005), map-based localization (Dellaert et al., 1999), and path planning based on trajectory scoring (Kelly &

Stentz, 1998). Actuator control for high-speed driving is different than for typical mobile robots and is very challenging. However, excellent solutions exist (Talvala, Kritayakirana, & Gerdes, 2011).

However, the general perception is unsolved for mobile robots and is the focus of major efforts within the research community. Perception is much more tractable within the context of autonomous driving. This is due to a number of factors. For example, the number of object classes is smaller, the classes are more distinct, rules offer a strong prior on what objects may be where at any point in time, and expensive, high-quality laser sensing is appropriate. Nevertheless, perception is still very challenging due to the extremely low acceptable error rate.

## 1.2 Driver's sensor configurations and sensor fusion

Driven by the demand for fewer accidents and increased road safety, the automotive industry has started with the implementation of driving assistance systems into vehicles several years ago. These assistance systems include adaptive cruise control, blind-spot detection, forward collision warning, and automatic emergency braking, among others. As main sensors for monitoring of the vehicle environment 2D cameras were used, in recent times also RADAR sensors have been increasingly employed for increased reliability. During the last years, it became more and more evident that the imperfectness of capturing the vehicle environment was one major limitation, often leading to system fail to function or to system switch off through auto detection. Particularly critical weather situations (snow, ice, rain, fog) and certain object properties (e.g., small-sized, nonreflecting, or transparent or mirroring obstacles) can lead to unreliable behavior. Also, mutual interference with other vehicles' active sensor units cannot be neglected with increasing penetration of deployed assistance systems.

Driving assistance is the first level of autonomous driving. Recent research efforts address higher levels of driving autonomy (Fig. 1.1 and Table 1.2), going beyond pure driver assistance systems toward fully autonomous driving, that

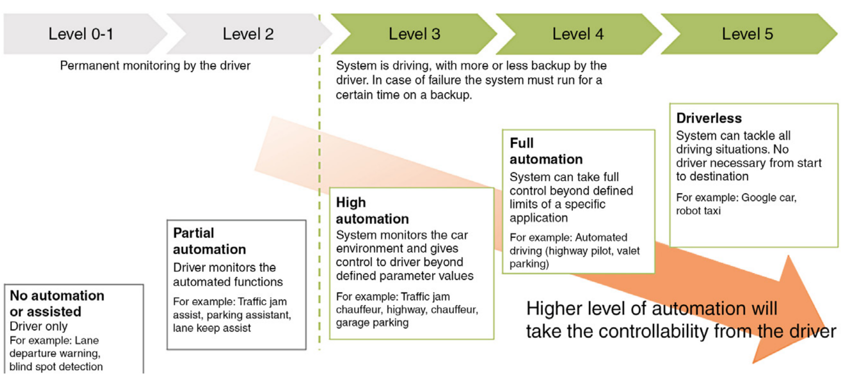


**FIGURE 1.1** **Evolution in ADF capabilities across SAE levels.**

**TABLE 1.2 Levels of automated driving defined by VDA J3016 and key performance figures for autonomous driving (Level 3+ requires advanced fail-operational dependability and ASIL D safety level).**

| Automation level | Functional description | Driver interaction | Perception redundancy | Dependability | Safety level |
|---|---|---|---|---|---|
| Level 0 | No automation | High | None | Fail-silent | QM |
| Level 1 | Driver assistance | Medium–High | Complementary | Fail-silent | ASIL A or B |
| Level 2 | Partial automation | Medium | Combining | Fail-safe | ASIL B |
| Level 3 | Conditional automation | Moderate | Partially overlap | Fail-safe | ASIL C |
| Level 4 | High automation | Seldom | Largely overlap | Fail-operational (single error) | ASIL C or D |
| Level 5 | Full automation | None | Fully overlap | Fail-operational (single error) | ASIL D |

is, VDA/SAE Level 3+. This involves fail-operational behavior and the highest levels of safety (ASIL D).

It is a common understanding that reliability improvement and advanced solutions for environmental perception (prerequisites for autonomous driving) can only be achieved by sensor diversity combined with data fusion approaches, due to the physical limitations of single sensor principles.

In the automotive domain (according to all major OEMs), robust and reliable automated driving will only be achievable by combining and fusing data of three different sensor systems: LiDAR, Radar, camera, exploiting their specific strengths as depicted in Tables 1.3 and 1.4.

McKinsey predicts an overall share of 78% for processors (37%), optical (28%), and RADAR sensors (13%) in 2025 (Table 1.5) among automotive semiconductors, reflecting the main electronic components of highly automated vehicles as announced by OEMs.

This is evidenced not only in market reports but also in the technology roadmaps of major OEMs. Strategy Analytics has analyzed the sensor demand for environmental acquisition and indicates high annual growth rates for RADAR, LIDAR, and 2D camera sensors for the coming years.

However, currently available solutions for highly automated driving have not reached readiness levels suitable for the automotive industry. Although system deployment costs for these demonstration vehicles are very high, this is acceptable and normal for novel low-TRL technologies. However, the inability to achieve fail-operational levels is a significant roadblock to their adoption.

**TABLE 1.3** Forecast of OEMs using sensor fusion technologies.

| OEM | Expected year for AD Level 3 launch | Key market | Other sensors fusion with LIDAR |
|---|---|---|---|
| AUDI | 2017 onwards | Europe, North America, China | Stereo Camera + LRR + SRR + LIDAR |
| BMW | 2018 onwards | Europe, North America, China | Stereo Camera + LRR + SRR |
| CADILLAC | 2020 onwards | North America, China | Radar + Mono Camera (LIDAR expected) |
| FORD | 2019 onwards | North America | Mono Camera + LIDAR + Radar |
| MERCEDEZ-BENZ | 2019 onwards | Europe, North America, China | SRR + LRR + Stereo Camera + LIDAR |
| TESLA | 2019 | Europe, North America | SSR + LRR + Stereo Camera |
| VOLVO | 2020 onwards | Europe, North America, China | SSR + LRR + Stereo Camera + LIDAR *LRR*, long range radar; *SRR*, short range radar |

Source: Frost & Sullivan).

**TABLE 1.4** Specific strengths of sensors.

| Sensor type | RADAR | LIDAR | 2D camera |
|---|---|---|---|
| Measures | Motion, velocity | 3D mapping | Texture interpretation |

## 1.3 Small, affordable, and robust LIDAR sensors will enable highly automated vehicles

LIDAR sensor technology requires the biggest push among all sensors in order to provide an economic solution. Presently, many demonstration vehicles use the HDL-64E-Laser-Scanner from Velodyne (priced at $80,000) for 360 degree scanning (in good weather conditions), which is mounted on the vehicles' roof. Even smaller LIDAR modules are available, although not fully fulfilling requirements for ADAS, and far too expensive to form a viable, scalable solution.

Therefore a low-cost $100 LiDAR sensor technology will be the major driver and enabler for robust and safe automated driving.

Fig. 1.2 depicts market estimations for the LiDAR sensor technology in the year 2021. According to Frost & Sullivan, a total of approximately 2.2 million passenger vehicles implementing LiDAR sensor technology will be sold in

**TABLE 1.5** ADAS: automotive semiconductor revenue distribution on device types in 2025.

| Technology | Percentage | Most important components |
|---|---|---|
| Processors | 37 | Microprocessing units, electronic control units, digital signal processors, and systems on a chip for signal processing |
| Optical semiconductors | 28 | Complementary metal-oxide semiconductor imaging sensors, LEDs, laser diodes and photodetectors |
| Radio-frequency semiconductors | 13 | Radio-frequency transceivers and radar processing |
| Memory | 12 | System memory |
| Mixed-signal | 8 | Power-management integrated circuits, bus transceivers |
| Other | 3 | Discretes, other types of sensors |

Source: McKinsey.

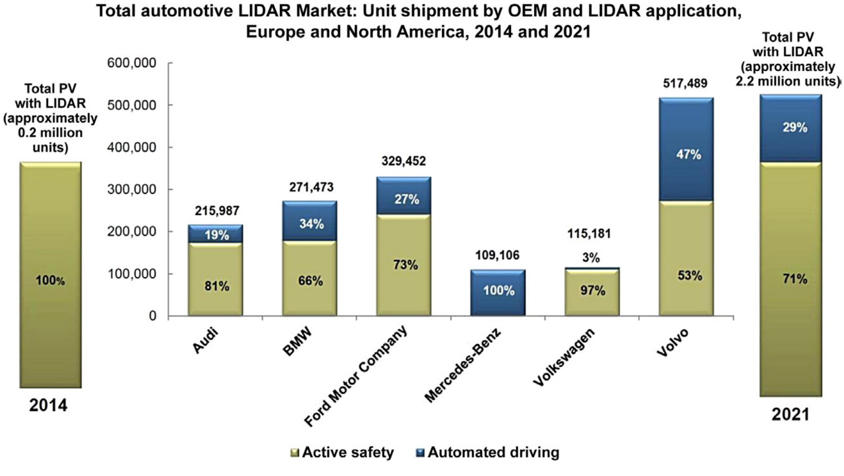


**FIGURE 1.2 LiDAR market estimations for 2021.** *(Source: Frost & Sullivan)*

2021. When taking into account, for instance, BMW's automated driving strategy (which plans to implement four LiDAR sensors into every automated car), the actual number of sold LiDAR sensor systems is by factors higher than 2.2 million units per year. These estimations outline the promising market potential of automotive LiDAR technology.

In addition to a vast market potential, the positive effects of funding this research proposal are manifold for Europe's industries. This research undertaking

**TABLE 1.6** State of the art LIDAR specifications.

| Sensor | Dimensional resolution | Range | Azimuth angle (degree) | Accuracy | Cycle |
|---|---|---|---|---|---|
| Quanergy M8-1 | 3D | 150 m | 360 | 0.05 m, -, 0.03° | 33 ms |
| Ibeo LUX | 2D | 200 m | 110 | 0.1 m, -, 0.125° | 20 ms |
| Continental SRL1 | 2D | 10 m | 27 | 0.1 m, 0.5 m/s, - | 10 ms |
| Velodyne HDL-64E S2 | 3D | 120 m | 360 | 0.02 m, -, 0.09° | 50 ms |

Source: de Ponte Müller, 2017

will tackle a promising new field of research by proposing and developing innovative approaches to enable a low-cost, reliable, and automotive qualified LiDAR sensor system. Therefore future advances will generate novel and outstanding technological know-how. As a further positive effect, the foreseen fundamental research and development activities will improve Europe's reputation as one of the world leaders in automotive and sensor technological innovation. Some key figures of state of the art laser scanners are provided in Table 1.6.

Due to the required fine-grained angle and range resolutions, one of the main problems with LIDAR is that they generate a huge amount of data, which needs to be locally compressed and prefused before transmitting them to the main unit for the next level of data fusion with other sensor information. One possible approach is to provide vector object lists at the interface to reduce the high data rates, as opposed to sending raw data.

## 1.4 RADAR

State of the art RADAR sensors either provide several fixed aligned, partly overlapping beam lopes or rigid phased-array structures at the receiving frontend. Typical single RADAR modules from Bosch are shown in Fig. 1.3 (long-range radar and mid-range radar), which are quite bulky.

Particularly for driving in urban environments, smart beamforming with high directionality will be necessary to properly capture the motion of other road users and outside traffic participants in the vicinity. For that reason, solutions for electronic beamforming must be developed to capture the whole vehicle environment and allow surround-vision based on radar (Fig. 1.4).

Beyond advances in hardware and beamforming, the state-of-the-art programmable radar signal processing will be improved. ADAS system sensors require a latency below 500 ms. The current baseline measure for interference


**FIGURE 1.3** **Bosch RADAR portfolio.**

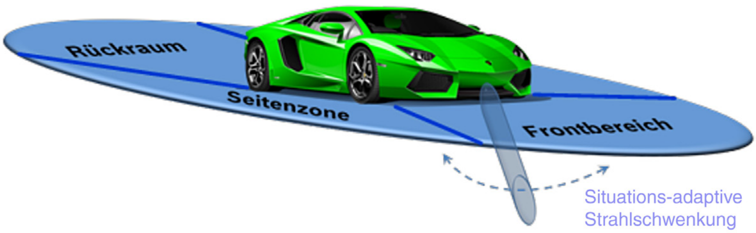


**FIGURE 1.4** **Situation adaptive beamforming for highly autonomous driving.**

shielding is the different characteristics of the FMCW signal. By monitoring the RADAR's radio channel conditions, both, the transmitter, as well as the receiver will be upgraded to cope with increasing interferences.

The state of the art in the RADAR modules is presented in Table 1.7.

**TABLE 1.7** State of the art RADAR sensor specifications.

| Sensor | Frequency | Bandwidth | Range | Azimuth angle (degree) | Accuracy | Cycle |
|---|---|---|---|---|---|---|
| Bosch LRR3 | 77 GHz | 1 GHz | 250 m | ±15 | 0.1 m, 0.12 $ms^{-1}$, - | 80 ms |
| Delphi ESR | 77 GHz | — | 174 m | ±10 | 1.8 m, 0.12 $ms^{-1}$, - | 50 ms |
| Continental ASR30x | 77 GHz | 1 GHz | 250 m | ±8.5 | 1.5 %, 0.14 $ms^{-1}$, 0.1° | 66 ms |
| SMS UMRR Type 40 | 24 GHz | 250 GHz | 250 m | ±18 | 2.5 %, 0.28 $ms^{-1}$, - | 79 ms |
| TRW AC100 | 24 GHz | 100 GHz | 150 m | ±8 | -, -, 0.5° | — |

Source: de Ponte Müller, 2017

It should be noted that particularly for urban driving environments, angle resolution is a crucial property.

## 1.5 Fail-operational E/E architectures

Several research attempts have been taken toward the implementation of fail-operational services for ADF. The need for fail-operational behavior means that in addition to conceiving a data-flow driven architecture capable of providing the requisite processing power for number crunching, the developed systems must also guarantee that in the event of an error (due to a sensor or hardware defect), the situation will be recognized and mitigated without impacting the vehicle's safety.

A common, non-fail operational system architecture is shown in Fig. 1.5. There are remote sensor modules, which, after raw data processing and data reduction, send their data via a wired interface to a central ECU with high processing performance, where ADF main functions for environmental perception, trajectory planning, etc. are implemented.

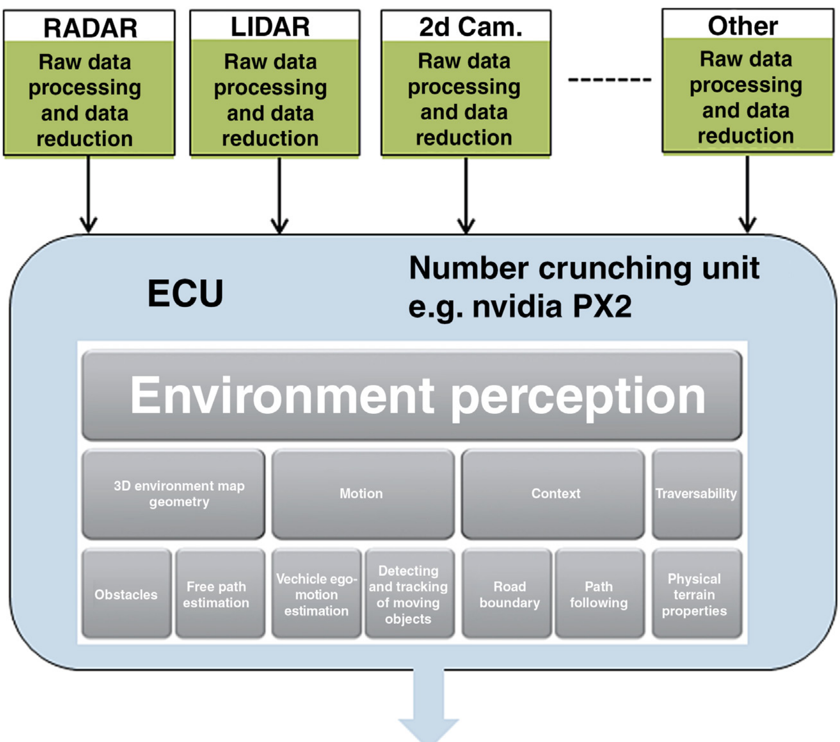


**FIGURE 1.5 Non-fail operational system architecture for autonomous driving functions.**

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Chapter 2

# Communication advances

## 2.1 Why vehicular communications?

The main motivation for the development of vehicular communications was and still is safety, in all its dimensions (vehicle, driver, passenger, pedestrian, and infrastructure). According to the World Health Organization (WHO), the result of road accidents worldwide in 2004 was 50 million injuries with 1.2 million of them being lethal (Peden et al., 2004) and the number increased to 1.4 million in 2016. This brought road accidents higher in the list of the leading causes of death in 2018 than in 2000 (https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death). The annual cost of car accidents has been estimated by the American Automobile Association (AAA) to surpass $300 billion in the United States (Meyer, 2008).

In light of the above, the main challenge of vehicular communications (also known as "V2X communications") designers and technicians is to develop systems that enable intra and intervehicle communication, as well as the communication with the road network or the power grid infrastructure, with passengers, pedestrians, and all other involved stakeholders in the vehicular communication value chain. The idea behind this is, of course, to use this communication in improving the overall transportation efficiency and eliminate accidents and, for this purpose, important vehicular communication research efforts take place nowadays in the United States, Europe, Japan, and China. Fig. 2.1 depicts at a high-level some solutions provided through vehicular communications.

## 2.2 Types (modes) of vehicular communications

When the concept of the Internet-of-Things is applied to the automotive industry then the new concept of the Internet of Vehicles (IoV) emerges. IoV assumes that every electronic device onboard of the vehicle is able to communicate (1) with devices of the road network infrastructure and the power grid (in the case of electric cars) and (2) the mobile devices of passengers, pedestrians, and cyclists using mobile internet technology (Ang, Seng, Ijemaru, & Zungeru, 2018). This transforms vehicles into smart nodes of a city-wide network. The different types of communication between vehicle devices and all other nodes of the network are detailed in the following.

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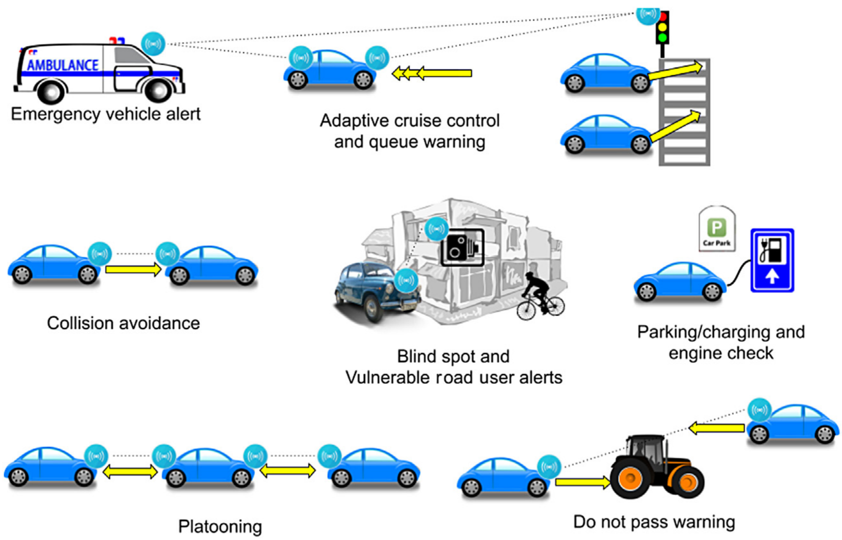


**FIGURE 2.1 Solutions provided using vehicular communication technologies.**

*Intravehicle communication* describes to interaction among versatile in-vehicle entities (sensors, actuators, ECU, data aggregators, decision support modules, etc.), as well as the transfer of data and information from one entity to another, so as to collectively (or in a distributed manner) decide upon the vehicle's behavior, either a priori (cognitive systems) or a posteriori (adaptive systems). It is also known as in-vehicle intelligence since it is the basis for an intelligent moving node of the IoV network.

*Vehicle-to-vehicle (V2V)* communication refers to the interaction of sensors, actuators, and other devices of (usually neighboring) vehicles with a vehicle's ECUs and decision support modules. The aim of this communication is to provide the vehicle with significant, almost real-time information on coordinates, direction, velocities, as well as other emergency situations that have to be taken into consideration before any situation handling.

*Vehicle-to-infrastructure (V2I)* communication refers to the interaction between the moving vehicle and the surrounding (usually static) transportation infrastructure. Indicative examples of entities belonging to the infrastructure are the traffic lights, traffic signs, on-road back-office, data centers, antennas, etc. The vehicle exchanges information with the aforementioned entities, so as to obtain an adequately good description of its context and thus enable immediate adaptation to external requisitions.

*Vehicle-to-network (V2N)* communication aims to provide entertainment and information services to the passengers taking advantage of available cloud services, so it is also known as vehicle-to-cloud (V2C) communication. In also provides security and firmware updates for the car software, shares engine information with authenticated services in order to provide preventive maintenance, helps in locating parking space and for planning a multi-modal trip while on car, thus making driving more enjoyable.

*Vehicle-to-pedestrian (V2P)* communication refers to the exchange of information between a vehicle and a pedestrian nearby, so as to mitigate a forthcoming danger. The idea is that V2P can early alert about vulnerable road users (pedestrians, bikers), which are not equipped with high-performance traffic processing sensors and actuators but may carry light beacons or smart watches that notify surrounding vehicles about their presence. The alerts can be valuable for the vehicle, especially in blind spots, such as road crossings or sharp turns.

*Vehicle-to-device (V2D)* communication describes the interaction between a vehicle and portable electronic devices that the passengers may carry. For example, V2C refers to the driver's smartphone that is connected to the car via Bluetooth and allows hands-free communication but also can extend the in-vehicle services through third-party applications that interact with the car. Another example is the monitoring devices that car manufacturers install in the cars, which collect engine data and allow the car manufacturer official smartphone applications to show reports concerning the health engine or provide preventive maintenance alerts.

*Vehicle-to-grid (V2G)* mainly refers to all types of electric vehicles from battery-only powered (BEV), to plug-in hybrids (PHEV), and hydrogen fuel cell electric ones (FCEV), which frequently connect to the power grid to recharge. During this process, the vehicles can also interact with the services provided by the power grid and can either sell electricity back to the grid (when they have enough capacity) or accelerate their charging rate.

All the aforementioned communication types are commonly used today for describing any type of interaction between the vehicle's control units, sensor, actuators, and the environment are termed by the broader term *Vehicle-to-everything (V2X) communication*. Whereas several modes of communication can be explored, if connecting a vehicle to any possible entity, the next section investigates the most commonly used standards communications technology for realizing V2X communications (Cleveland & Morris, 2015).

## 2.3 Cellular V2X (C-V2X) and the case of 5G

The standardization of the Cellular Vehicle-to-Everything (C-V2X) technology has been finalized by 3GPP in 2017 (GSMA, 2017) and aimed at connecting vehicles with the road network infrastructure, with all other types of road-users and with the cloud. It soon attracted the interest of car manufacturers who acquire mobile and short-range communication technology expertise and develops C-V2X connectivity to their vehicles. The advantages of C-V2X over previous communication technologies for the automotive industry are among others:

- They use the wide coverage of existing LTE networks and take advantage of the already tested security features.
- They allow high-speed and reliable communication even in dense traffic.

- They provide both short and long-range data transmission and are thus ideal both for intra and intervehicle communication.
- They are part of the plan for establishing 5G connectivity.

The combination of short and long-range connectivity and reliability makes C-V2X an ideal low-cost solution for manufacturers that aim to build a safer and more comfortable driving experience. At the same time, C-V2X is becoming the basis for developing advanced security, safety, and car maintenance services such as reliable car diagnostics, flexible car insurance contracts, emergency call, infotainment onboard, etc.

C-V2X is also compatible with the existing cellular roadside infrastructure thus reducing the cost for installation and maintenance of new road-network facilities for local administration and moreover for agencies that control highway systems. Finally, C-V2X stands on the security services developed in the existing cellular networks and offers two communication modes—one for direct communication between moving nodes (vehicles, pedestrians, etc.) and the infrastructure, which is mostly used for safety and emergencies and one for network communication, which uses the conventional mobile network for communicating less crucial information or information that does not have to be real-time or media for entertainment.

The use of C-V2X can be beneficial in many scenarios that promote road safety and improve the efficiency of transport networks:

1. In the *vehicle-platooning* scenario, vehicles communicate with each other in order to form a convoy, where autonomous vehicles travel in a close distance from each other, which normally would not be safe for human drivers to keep. The result is better road space usage and savings in fuel consumption because of the adaptive cruise control. The scenario is of high interest in the freight transport industry that can significantly improve the efficiency of goods transport.
2. In the *cooperative-driving* scenario, vehicles communicate with each other in cases of emergency, when they change their trajectory (e.g., when they change lanes or brake suddenly), or when they want to change route (e.g., in a U-turn or a car pass over the opposite lane)
3. In the *queue-warning* scenario, the roadside infrastructure communicates with the vehicles to warn them for construction works along the road, or queues that have been formed in from of them, giving them time to decelerate smoothly and thus avoid accidents and reduce consumption.
4. The *collision-avoidance* scenario assumes that in case of an emergency braking, a sudden lane change, a car accident, or any other obstacle ahead either the nearby cars using their cameras or the road infrastructure using sensors will be able to early understand the case and inform any vehicle that is approaching to either to slow down or to brake immediately, if this is the case. The nearest approaching vehicle will also transmit the information to the vehicles that follow thus reducing the risk for a car pileup.

5. In a similar *hazard-ahead* scenario the C-V2X can extend the visibility of a vehicle around blind corners, through heavy fog or a high lorry that hides the driver's horizon. V2V communication can be used to share the camera or other sensor feeds between neighboring vehicles.
6. In the *electronic toll-payment* scenario, the V2I interaction can be used to resolve toll payment as the vehicle is approaching the tolls, thus removing the need to stop or even to slow down. This is expected to reduce toll traffic and save a lot of fuel for vehicles that frequently use roads with tolls.

As a summary of the above scenarios, we can say that the combined use of sensors, actuators, and the C-V2X communication under predefined scenarios can boost the popularity of autonomous vehicle systems and increase people's trust in them, thus leading to a wider acceptance of autonomous and self-driving vehicles.

As a case study of C-V2X, the main concept of several recent research attempts lies in the provision of quantifiable evidence, frameworks, and tools to enable the exploitation of 5G communication technologies for the provision of cooperative, connected-automated mobility (CCAM) solutions for vehicles of SAE Level 3 and beyond, offering low-latency, high-reliability, and minimum road-infrastructure costs. This concept has arisen from several findings within the international research literature and industry, which have revealed that with the increasing SAE automation levels in vehicles, the need for connectivity and coordination becomes a fundamental prerequisite, for ensuring fail-operational perception and control, which is indeed necessary for the provision of advanced CCAM services and applications. So far, attempts to bring the above into reality have either been inefficient in terms of technological parameters (e.g., increased latency, reduced reliability, and dependability) or in terms of high-infrastructure costs that require investments of questionable cost-effectiveness.

Several recent research attempts advocate that 5G is the ideal candidate to provide the next level connectivity necessary to fulfill the stringent requirements of autonomous and paves the way for the provision of previously unfeasible CCAM services for vehicles of SAE Level 3 and beyond. This is due to the fact that (among other benefits discussed further), 5G provides extremely high and dependable connectivity with significantly lower-maximum latency (1–10 ms end-to-end), and higher data transfer rates compared to existing technologies. It also has a more efficient market penetration model that is more pervasive and cost-efficient.

A first step toward the technological exploitation of 5G communication infrastructures in ITS as an alternative to existing approaches is illustrated in Fig. 2.2. Instead of investing in expensive Road Side Infrastructure/Units (RSU) that will support the IEEE 802.11p communication standard, a combination of the current 4G technologies, where appropriate, with the 5G technology can be used for developing a more cost-effective solution. Fig. 2.3 exemplifies the concept in a cross-border scenario (the so-called "corridors" recommended by the EC) (EC, 2019), where the problem of disrupted connectivity can be resolved by the exploitation of 5G communication infrastructures.

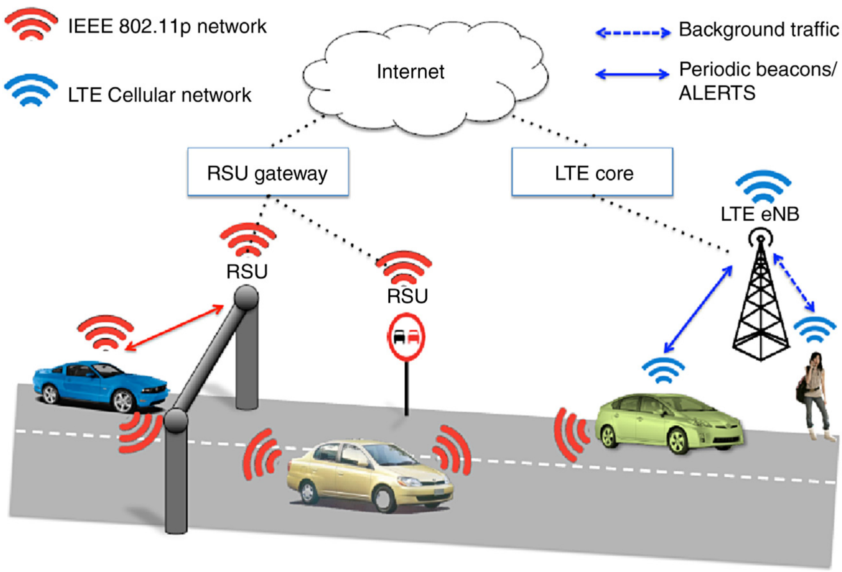


**FIGURE 2.2 First illustration of C-V2X.**

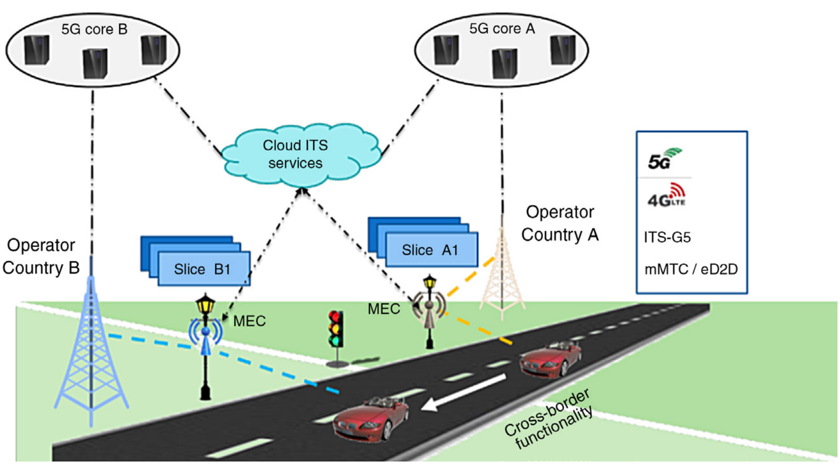


**FIGURE 2.3 Illustration of C-V2X in a cross-border (corridor) scenario.**

In addition, as shown in Figs. 2.2 and 2.3, in order to qualify 5G as the optimum solution for previously unfeasible CCAM services, not only the telecommunication infrastructures must be advanced, but also:

1. road infrastructures need to be advanced so as to be able to support 5G CCAM use cases (to be demonstrated in the cross-border pilots, as well as tested in the local one), in terms of sensors, distributed storage of data, advanced functionalities for fail-operational perception;

2. in-vehicle intelligence should be enhanced, through enablers for supporting novel concepts, such as, for example, 5G-D2D, so as to cater for ultra-low latency next-generation V2X communications;
3. well-defined communication processes must be established, along with interfaces for plugging-in disparate data sources enabling local and cross-border CCAM. For example, the processing of 5G-oriented information can be performed by mobile applications that constantly provide the RSSI/RSRP signal level that the phone gets from the nearest BTSs (around ten stations are used). This information can be combined with the location of BTS/Node-Bs, the RAT (GSM, UMTS, LTE, etc.), and other information provided by the 5G operator and using multi-angular calculations can be used to specify the coordinates of a 5G-enhanced vehicle, its direction, its velocity, etc.

Virtualization and resource sharing are mainstream flexibilization strategies to achieve stringent performance goals in cellular networks (Philip, Gourhant, & Zeghlache, 2011). Diverse technologies (RAN virtualization, NFV, SDN) have stemmed from this need for flexibility allowing, among other benefits, the implementation of network slices—virtual networks with specific functionality for a particular service or customer. This functionality can be used to differentiate traffic classes with diverse requirements or even to implement virtual mobile operators (VMOs).

For example, the recent SONATA project (Dräxler et al., 2017) has addressed aspects such as orchestration of VMO resources. The MPC project has proposed an SDN-based NFV-oriented mobile packet core to facilitate the dynamic provisioning of network functions (Sama et al., 2015). Most existing approaches are generalist, in the sense that they are neither optimized for particular applications nor for particular traffic classes. Instead, they exploit virtualization to differentiate the diverse cooccurring traffic classes in traditional telcos seeking to balance the quality of service levels. For example, the exhaustive survey (Bizanis & Kuipers, 2016) recognizes the interest of SDN technology to "group" IoT traffic with similar requirements, but not the possibility of specialized IoT virtual operators within a multioperator architecture.

Orchestration (Foukas, Nikaein, Kassem, Marina, & Kontovasilis, 2017) and SDN technologies play key roles in the "specialized" scenario we foresee. Regarding SDN control, it must react to migration decisions rerouting flows between packet core processes. Besides, PHY-level RAN slicing may be integrated within the same SDN control architecture. Multi-operator or multi-slice SDN control should be driven by global optimization of the performance goals of the actors in the scenario, according to its particular trade-offs (central processing vs. edge computing, PHY costs vs. peak rates, etc).

Regarding RAN slicing, different works have studied it considering a particular PHY layer. For example, the COHERENT project (www.ict-coherent.eu) separated the RAN data and control planes and coupled the latter with the virtualized control functions. This way, it was possible to control the OpenAirInterface-based RAN infrastructure following an SDN approach. The 5G-EmPOWER tool kit was used to demonstrate a Wireless LAN hypervisor that could follow the dynamic traffic variations as seen by the different network tenants (Koutlia, Umbert, Garcia, & Casadevall, 2017). Other projects have handled the traffic of different network slices at the LTE-scheduler level (or its equivalent in other technologies).

Moreover, the successful deployment and optimization of V2X networks enabled by existing 4G/5G network infrastructures require a solid understanding of the radio-propagation conditions in high-mobility scenarios, which allows for validating the suitability of the networks for CCAM solutions, especially in terms of throughput, latency, and reliability. Drive testing using off-the-shelf tools based on data gathered from commercial user equipment terminals such as smartphones is a common approach to the problem. However, such testing solutions all too often limit the evaluation to high-level figures of merit and depend on closed hardware and software tools, which are hardly customizable to incorporate new functionalities. Additionally, data collected from MNO infrastructures using mobile smartphones and/or on-board devices must be also validated by means of independent measurements, especially in specific-vehicular scenarios such as dense urban environments, viaducts, or tunnels.

The main advantage of testbeds is that they are not developed for a specific experiment or waveform and, at the same time, they only transmit and send the signals over-the-air in real-time, whereas the signal processing tasks are carried out in real-time and/or offline from the recorded signals. Since the advent of hardware solutions for a software-defined radio, testbeds became flexible, powerful, and affordable tools for assessing wireless communication systems (Caban, Naya, & Rupp, 2011), including channel characterization (Domínguez-Bolaño, Rodríguez-Piñeiro, García-Naya, & Castedo, 2017). Additionally, they can incorporate sophisticated synchronization mechanisms or geo-reference the acquired data, making them suitable for high-mobility scenarios.

## 2.4 Wireless access for vehicular environments (WAVE) and its migration toward IEEE 802.11p

The history of V2V and V2I communication goes back in 1992 when the United States started research on the Dedicated Short Range Communication (DSRC) protocol. With the United States, Japan, and Europe working on DSRC it soon evolved to a standard of the IEEE 802.11 family of standards in 2004. Initially it was based on IEEE 802.11a standard and the wi-fi architecture and used the 5.9 GHz band. In an effort to support high-speed moving objects (such as vehicles in highways) the IEEE working group improved the protocol and simplified the communication mechanisms, thus leading to Wireless Access for Vehicular Environments (WAVE) amendment of the IEEE 802.11 standard, which was intended to be used by intelligent transport systems for short-range communication (Eichler, 2007).

The WAVE standard focused on the immediate, stable, and secure transmission of traffic information collected by vehicles and sensors in the road network infrastructure. It is now used both by onboard equipment and road infrastructure when they exchange real-time traffic information. The benefits from the use of wirelessly transmitted information are multiple and include increased road safety, fewer congestions, and faster and energy-efficient transport. WAVE includes the IEEE 802.11p standard (Jiang & Delgrossi, 2008) and the IEEE 1609 (IEEE, 2007) upper layer communication family of standards. The latter contains a set of standards that define the details of V2V and V2I communication such as (1) the IEEE 1609.2 standard that handles communication security, (2) the IEEE 1609.3 standard for setting up and managing WAVE connections, and (3) the IEEE 1609.4 standard which combines IEEE 802.11p Physical (PHY) layer and Medium Access Control (MAC) layer to provide better management of the higher layers across multiple channels.

The IEEE 802.11p standard has been used for V2V communications for many years (Bai & Krishnan, 2006; Vinel, 2012). It has most of the features of the IEEE 802.x family of standards, which means that it is simple and provides mechanisms for distributed MAC. It has not yet been fully adopted, mainly because of the reliability, resilience, and stability issues that it as. However, its main issue is that it is not open and requires that both communication parties use the same equipment. Several automotive applications on the market are used the IEEE 802.11p standard and test it on real cases, and many manufacturing companies (of both vehicles and vehicle electronics) are launching research projects in collaboration with the academia in order to study all aspects of the protocol application in the V2V and V2I communications. The applications can be grouped into three major types, depending on the aspect that they examine—(1) safety, (2) traffic, and (3) user comfort.

### 2.4.1 Safety-related applications

The applications in this group set many real-time response constraints that the IEEE 802.11p standard does not provide alone. So they perform several extensions in order to allow the development of safety applications (Bohm & Jonsson, 2009). The communication can be either multipoint or p2p but requires low-latency for real-time interaction. Information, such as position and speed can be exchanged between vehicles (V2V) and collected in each one of them in order to allow drivers to have a better idea of the surrounding traffic. This is extremely helpful in bad weather conditions that reduce driver's vision such as heavy snow, rain, or fog or in blind-road spots (e.g., at intersections, sharp turns, or behind-bulk vehicles). Another example is when an emergency-vehicle needs to inform the vehicles in front for the urge to reach a destination as soon as possible. This can be done by using the communication standard to transmit an emergency message. The latter scenario also makes use of V2I communication by sending a message to the traffic management operators to intervene in the traffic lights all along its path, thus early reducing traffic ahead. In the opposite way, the emergency-vehicle driver is alerted for possible queues in front in order to prevent a possible collision.

### 2.4.2 Traffic-management applications

This group of applications is based on information exchange about vehicles' position and speed in order to collect useful data for real-time traffic analytics by the traffic management operators. Analytics can support better traffic planning as well as real-time management of emergencies. By collecting traffic data, it is easier to regulate the traffic during a traffic jam or redirect traffic in order to reduce delays. A more advanced application can be the implementation of a smart network of traffic lights that will collect information about the amount of vehicles waiting at all times and the delays they face and will consequently adjust green light times in order to provide a smoother car flow and reduce traffic.

Using V2I communication, the road network operators are able to collect information about vehicle flows and loads in road junctions and provide traffic information to the drivers in real-time, thus helping them to take informed decisions about the path to follow in order to avoid traffic.

The Electronic Toll Collection is another application that reduces traffic and has been quite popular among many countries. The ETC system allows the faster collection of tolls, gives the ability to create more flexible charging policies, and reduces the congestion in tolls. Using the WAVE protocol, the on-board transmitter can communicate with the antenna installed on the toll lane and allow the vehicle to pass without stopping or reducing speed.

### 2.4.3 User-comfort and infotainment applications

The aim of such applications is to increase the comfort level of drivers and passengers and provide them with entertaining and informative content. Information may relate to traffic or weather conditions ahead or can be completely irrelevant to driving allowing passengers to relax with films or music that is streamed to their vehicles on demand. They can also upload information to the cloud and share it, but since it is not critical for driving it will have low-priority concerning the use of the available bandwidth. The ongoing research in this field inflates the expectations. However, the IEEE 802.11p has not been designed for this purpose and can hardly support them in the case of a fast-moving vehicle or a vehicle that is moving on a rural area, away from wifi hotspots and routers. Such applications also raise a security issue, since in order to provide connectivity to the cloud a lot of routers must be trusted in the path. As an alternative, such services examine other technologies such as 3G or 4G that have been designed for such tasks.

## 2.5 IEEE 1609 family of standards

In order to cover dedicate short-range communication needs at all the layers of the communication stack, the IEEE 1609 family of standards defines the architecture of the network, the model of communication as well as the management structure and the security mechanisms for providing high speed wireless connectivity (>27 Mb/s) in the short-range (<1000 m) and with low-latency between the vehicle and its surroundings.

The standard defines a simple architecture that comprises three main components—(1) the On-board Unit (OBU) in the vehicle; (2) the Road Side Unit (RSU) in the road infrastructure; and (3) the WAVE interface for the V2V and V2I communication.

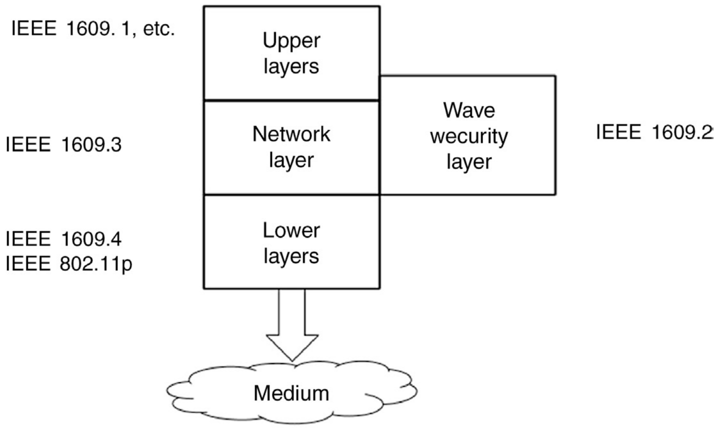


**FIGURE 2.4 IEEE 1609 family of standards.**

In the middle (network) layer, the IEEE 1609.3 standard defines the setup and management process for the WAVE connection. In the lower layers, the IEEE 1609.4 standard stands above IEEE 802.11p and allows the upper layers to communicate using multiple channels, without having knowledge of the physical layer parameters. The standards extend the physical channel access defined in WAVE and using IEEE 1609.1 define how applications will communicate using the WAVE interface. The relationship among IEEE 1609 and IEEE 802.11 standards is depicted in Fig. 2.4.

## 2.6 SAE J2735

The SAE J2735 is a standard that is frequently used in V2V communications. It is essentially a Message Set Dictionary for DSRC and is maintained by the Society of Automotive Engineers (http://www.sae.org). The standard defines the set of messages that can be used in DSCR or WAVE communications, and the data frames and elements that applications have to use in order to comply with the standards of DSRC/WAVE communication.

SAE J2735 focuses on messages and the structure they must have and provides all the information necessary to application developers that need to interpret the exchanged messages that follow the DSRC standards. More specifically, the message sets define the content of all messages delivered at the application layer and at the same time allow us to calculate the payload for transmitting the message at the physical layer. The message sets rely on the lower DSRC protocol layers of the DSRC protocol for the appropriate message delivery from the application that runs to the vehicle (e.g., in the vehicle's OBU) to the application hosted on a roadside unit. As it holds with WAVE and DSRC, the lower layers follow the IEEE 802.11p directions and the upper layers comply with the IEEE 1609.x family of standards. This standardization of message sets, data frames and data elements enhances the interoperability of DSRC applications at the data level.

The message set dictionary of SAE J2735 contains 15 messages, 72 data frames, 146 data elements, and 11 external data entries. The most important type of message is safety-related and is the message that informs surrounding vehicles and the infrastructure about the existence of a vehicle. This "heartbeat" message increases the amount of information of nearby vehicles and assists their autonomous driving mechanisms to respond better. This basic type of message contains temporary identity information and a timestamp, 3D position information and the associated accuracy, speed, heading, and acceleration information, as well as the steering wheel angle, the brakes' status (on/off), and information about the vehicle size.

Apart from the heartbeat message, there exist other message types such as:

- A template-based (a la carte) message, which is composed of message elements that the sender chooses. This type of messages allows fast and flexible data exchange, with a small degree of customization.
- Emergency vehicle approaching message that alerts surrounding cars and the infrastructure that an emergency vehicle is approaching the area.
- Generic transfer message, which is the main interface for V2I messages.
- Probe-vehicle data message, which contains vehicle-mobility information that can be used for applications that analyze traffic conditions.
- Common safety request message that is used for exchanging basic vehicle information for car-safety applications.

## 2.7 LED-enabled visible light communications (IEEE TG 802.15.7)

Light-emitting diodes (LEDs) are quite popular choices for display and illumination applications. The offer high-brightness, low-power, and heat-dissipation, and live longer than conventional lamps. Finally, they are used widely for road illumination, traffic signs, and the headlights of vehicles. Another advantage of LED technology is that diodes can be modulated at high speeds thus allowing them to be used for data transmission tasks. Visible Light Communication (VLC) on top of LED offers increased reliability, at a low-cost and with a reduced-energy footprint. The transmission is free of interference, whereas the LED technology is easy to integrate and interoperable (Bouchet et al., 2010; Komine, 2001)

It is important to notice that the national roadmaps for transportation in many countries assume that road infrastructure elements, such as traffic signs and traffic lights will be soon equipped with sensors, actuators, and embedded processors and the same elements employ or are soon planned to use LED technology for display or illumination purposes. On the other side, vehicles are also equipped with LED (e.g., LED head lights), which makes LED technology and VLC ideal candidates for V2X communications (Wook, Haruyama, & Nakagawa, 2006). In this scenario, LED lights in vehicles can be used to transmit data from the vehicle and the infrastructure or other vehicles in a fast, reliable, and energy-efficient way.

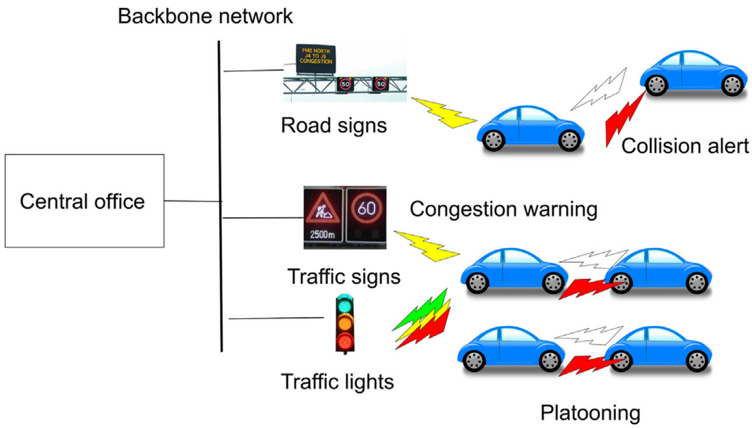


**FIGURE 2.5** **VLC as a standard for V2X communications**.

Fig. 2.5 provides an overview of an ITS that relies on VLC for V2V and V2I communication. The system comprises several infrastructure modules that connect to the backbone network from various access points (traffic lights, road signs, etc.) and transmit data to the central office using existing wired or wireless communication technologies (fiber-to-the-X, ADSL, etc.). The central office is responsible for the overall information management and uses the access points to communicate the appropriate information to the appropriate vehicle (V2I). The V2I and V2V connections are performed using VLC technology.

LED-based connectivity can be used for:

- Sending messages (downstream) from the traffic lights to the vehicles using all the three colors of the traffic light (red, green, yellow) to maximize bandwidth.
- Sending messages (downstream) from road and traffic signs to the vehicles. Signs have a single-color LED that is used for this purpose.
- Sending information (upstream) from the vehicle to the nearby access points. The vehicle's white LED lights can be used for this task. IR LEDs can also be used during the day.
- Sending data (upstream) from the vehicle
- Exchanging information (upstream/downstream) between nearby vehicles. The front and rear (e.g., brake) lights of two cars can be used to transfer data between the vehicles. The use of IR LEDs must also be examined for the daytime.

The VLC technology can become a sustainable solution for developing transportation systems, and more specifically "Vehicle Autonomic Management Systems" (VAMS) since it is reliable, and resilient to any interference and has a low-infrastructure cost and low-energy footprint.

## 2.8 Bluetooth

Bluetooth is a widespread communication technology that offers simple and secure wireless connectivity. It is used by billions of devices worldwide aiming to replace cables and maintain security in short-range communication. Apart from this, Bluetooth technology offers ubiquitous access, at low power and at a low cost. In the automotive industry, Bluetooth technology came as an enabler for hands-free smartphone usage while driving, whereas in healthcare Bluetooth glucose-monitoring devices are used by diabetics to monitor blood-glucose levels. Recently Bluetooth has been employed for intravehicle communications that transmit engine-related information directly to the driver's dashboard.

The Car Working Group (CWG) is responsible for the development of new features that employ Bluetooth technology in vehicles since 2000. The Bluetooth Core Specification (https://www.bluetooth.com/specifications/bluetooth-core-specification/) defines a uniform structure for the devices that use it to communicate with each other, which is based on the pairing of devices at a first step and the exchange of data at a second step. Bluetooth global acceptance has been achieved based on the easiness and reliability of connectivity, which guarantees that any Bluetooth device will be able to connect to all other Bluetooth devices in proximity.

Such short-range connections, among Bluetooth devices, allow creating ad-hoc networks, which are also known as *piconets*. Piconets are established automatically as one device enters the radio proximity of the other, which significantly simplifies the process of connection and disconnection from a network. A device can belong to multiple piconets at the same time and can communicate with up to seven devices within the same piconet, thus increasing the possible network structures that can be achieved. In several cases it is enough for the device's Bluetooth wireless option to be set to "visible" and all other devices in the area can track it, by following it directly or by collecting information from nearby access points that connect in a mesh.

Bluetooth technology can transmit both data and voice transmissions, thus allowing multiple innovative applications to be developed, that combine voice commands and calls, with data transfer for tracking and data collection and synchronization.

Although the core specification defines a minimum range of 10 m, manufacturers can set their own limits to cover a wider range or to provide a less energy-consuming (but shorter-ranged) solution. As a result, the Bluetooth range may vary depending on the application and on the radio class used in each case:

- Class 3 radios—have a range of up to 1 m.
- Class 2 radios—have a range of 10 m and are the most commonly used in mobile devices.
- Class 1 radios—have a range of 100 m or 300 ft and are usually employed in industrial applications.

Bluetooth technology employs the 2.4 GHz ISM band which is unlicensed and open in most countries. The Class 2 radio that is used in most cases operates at 2.5 mW and is shut down after a period of inactivity in an effort to keep power consumption at a low-level. Bluetooth uses adaptive frequency hopping (AFH) at 1600 hops/sec which employs a spread spectrum of 79 frequencies at 1 MHz intervals. The adaptive technology detects other devices and wireless technologies that use the same spectrum and switches to empty frequencies, thus achieving reduced interference with other devices and maximum use of the available frequency spectrum. With the adaptive hopping, Bluetooth achieves maximum performance even when more wireless technologies use the same spectrum.

The latest Bluetooth version 4.0, or Bluetooth Smart, provides ultra-low power consumption at all operating modes which makes it ideal for small battery-powered devices that can work for using standard coin-cell batteries, It is a low-cost technology, supported by multiple vendors, offers interoperability and an enhanced connectivity range, allowing device to connect directly with existing laptop, tablet, or smartphone Bluetooth nodes.

Apart from intravehicle and V2V communications, Bluetooth can be used for V2I communication scenarios, for example, for allowing vehicles to interact with the traffic signal system. Many companies that provide devices for the road infrastructure are using Bluetooth to collect traffic flow information. The Bluetooth-enabled devices are embedded in the transportation network infrastructure, for example, at major intersections or bus stops and terminals and collect anonymous Bluetooth signals transmitted by on-board Bluetooth devices or the pedestrians' smartphones. They use the collected data to calculate traffic journey times and estimate passenger and vehicle flows. The device identification is achieved by using the unique MAC address that each Bluetooth device carries and match MAC addresses across locations in order to accurately measure journey time, thus solving any privacy concerns which are usually associated with probe systems.

## 2.9 ETSI and CEN standards for V2X communications

Two European standardization bodies, (ETSI and CEN) are constantly conducting research on new standards that can further improve communications in the automotive and transportation domains. In this respect, the connected-car standard (EC, 2014) defines how V2V and V2I communications should be in Europe and lists all potential security risks from cyber-attacks against the wirelessly connected vehicles. The two technical specifications described in Release 1 of ETSI ITS are:

- EN 302 637-2: which defines the Cooperative Awareness Basic Service
- EN 302 637-3: that specifies the Decentralized Environmental Notification Basic Service.

Both standards were developed under EC Mandate 453, define the message sets that can be used in safety-critical applications of cooperative ITS and incorporate the findings from the past interoperability testing workshops (Plugtests) that ETSI has organized. The Cooperative Awareness Service, described in EN 392, assumes information exchange between road users (cars of all types, bicycles, motorcycles, and pedestrians) and the infrastructure (road signs, traffic lights, and barriers), which includes position and movement data, as well as identification and other properties, and achieves increased awareness among participating nodes. EN 302 637-2 specifies the message (Cooperative Awareness Message) syntax and semantics and defines how messages are handled. EN 302 637-3 defines the Decentralized Environmental Notification (DEN) Basic Service for sending warnings in the case of road hazards. The respective warning message (DENM) contains information about the road or traffic conditions and in a typical, ITS scenario is sent from an ITS station to all surrounding vehicles using V2I communications. All vehicles that receive the message, process it and present relevant information to the driver who can take an informed decision.

## 2.10 Conclusions

It is evident from the current technological status of automotive communications, that short-range communication is used to complement traditional wifi technology and provide device communication of various granularity, ranging from intravehicle transmissions to interaction with other vehicles and the infrastructure. The need for common and standardized technologies and protocols for data communication is clear and when achieved is expected to boost interoperability and allow the successful deployment of large-scale ITS applications that support the ad-hoc connectivity of vehicles and other mobile devices.

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Chapter 3

# Computing technologies: platforms, processors, and controllers

## 3.1 Introduction to modern automotive high-performance computing platforms

Hard real-time applications in the automotive field, such as autonomous driving (AD), are particularly demanding from a technical and environmental perspective since they have high complexity and require a lot of computational power and energy in order to operate. Such innovative applications emerge in automotive but are equally suitable for other domains such as machinery, medical, and avionics as well as in other cyber-physical domains. The challenges for such applications for the automotive domain is that they have to be fully operational in difficult environmental conditions, for example, in temperature ranges between −40 and 120°C, exposed in high humidity levels and in mechanical and chemical stress, and must have a life span that exceeds the 15 years. The functions to be implemented have to be available in real time and fulfill several safety and security requirements. Therefore automotive could be treated as the appropriate touchstone for the deployment of computation technology.

The following main trends are currently driving innovations in the automotive industry:

- The transition to *electric vehicles*, with mechanisms that will completely replace gas motors.
- *Automated driving* and supporting systems, such as the advanced driver assistance system, which includes emergency braking, cruise control, lane keeping, and other assistive functions.
- The *Connected Car* concept that implements connectivity between the car and other vehicles and the car and the road network infrastructure.

These trends will have a clear impact on the future E/E (electrical/electronic) architecture, related hardware, and software leading to a dramatically higher overall system complexity and required computational performance [electronic control units (ECU) as the "System," a car as the "System," or fleets as the "System"].

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From what we see today three key topics drive the growth of in-vehicle and backend performance needs:

- Over the air software update enabling new services and features by software after SOP;
- New updates during product lifetime require scalable HW concepts and additional reserved performance “headroom” for future services introduced after the start of production;
- Cybersecurity requirements to preserve operational and functional safety.

## 3.2 Consequences for vehicular electrical/electronic (E/E) architectures

Resulting from these automotive innovation drivers, a dramatically increased computing performance is required. The 100 and more ECUs that today are provisioned in E/E vehicular architectures are hardly able to cover the increasing requirements for high computing performance, which will guarantee a real-time response on emergency, operational and functional safety, and security to external threats and attacks. The novel autonomous vehicle E/E-architectures must be based on a few HPC solutions that comprise specialized hardware with graphics processing units (GPUs) and special controllers and are able to accomplish multiple perception tasks in real-time without fail (Kovač, et al., 2019).

In order to achieve real-time *vehicle perception* and build a reliable model of a vehicle’s surroundings, it is necessary to collect and process heterogeneous sensor data, to be able to provide on-the-fly processing and analysis of video streams, and be ready to integrate information and knowledge from various sources and in varying condition in order to take correct decisions. It thus relies on the data fusion and behavior prediction capabilities of deep learning models (e.g., for computer vision), which must be low latency, low complexity, and economic in terms of processing power needs. A feasible solution to this complex problem seems to be the replacement of embedded automotive processors that are incapable to provide advanced data fusion services (from data-intensive sensors such as LIDARs, ultrasonic radars, and cameras), with high-performance processors such as those used in HPC centers and their combination with specialized MCUs for the automotive example. All the issues that emerge for the automotive industry concern the management of big data that result from the various sensors, the onboard application of deep neural network models for the real-time processing of such data at inference time and the offline training of massive amounts of historical data at cloud or server level. All such solutions strongly rely on transparent and secure communication between car-embedded HPC and cloud-based HPC. This perspective leaves space for many collaboration opportunities between the automotive and high-performance computing industry both in terms of novel architectures, as well as in terms of hardware and software that will efficiently cover the automotive industry needs.

The training of machine learning models on large quantities of historical data and their application on real-time data will allow developing solutions for traffic estimation, travel time prediction, and vehicle breakdowns. The adoption of machine learning in the automotive industry can also offer route recommendations based on fuel consumption and even parking availability. To introduce safe, personalized, and predictable AD experiences, OEMs and Tier 1 suppliers are investing heavily in machine learning and predictive analytics. Predictive algorithms and artificial neural networks help smart vehicles see and interpret road environments up to 99.8% better than human drivers.

The next generation of ECUs that host deep learning models is a fact and the market interest for them is steadily growing according to recent market researches (Amsrud & Garzon, 2018). The volume of data that such units are expected to process strengthens the need for integrated deep learning models that will adapt to any condition and will be an intrinsic part of the modern automotive electronics systems.

The need for local data processing and adaptability to the conditions is evident in autonomous vehicles, in drones and robots that navigate in open and uncontrolled environments. Local data preprocessing in combination with reinforcement learning algorithms that run locally will allow such systems to adapt to any condition, avoiding the network latency and other security risks that cloud processing-based solutions can face. An indicative example is the extraction of traffic information directly from the onboard camera of vehicles, using computer vision models that run near the sensor and not in the cloud. This is expected to reduce the communication overhead and balance the computational load between the cloud and the edge devices. The development of low-cost and low-consumption hardware that will be able to run on the edge and successfully and efficiently analyze video sequence is still challenging, although many steps have yet been accomplished. The energy consumption that is still high, the limitation in computational power and memory and their high cost are a few of the factors that still keep embedded platforms far from being the common practice for automotive applications.

Although Google and other AI specialists have developed deep learning models for computer vision that have an outstanding performance in scene decomposition and object identification, that in some cases outperforms even the human eye (which has a 5% error rate), they still rely on large scale hardware architectures. Such architectures comprise multiple GPUs or tensor processing units that can process efficiently huge amount of computation loads and are pushing toward the use of deep learning models for computer vision.

On the other side, Tesla takes advantage of the NVidia technology (the Drive PX2 processor), which is embedded in the on-board driving control unit (Lambert, 2017) and offers advances deep learning functionalities for processing ultrasonic, camera, and radar data and supporting the vehicle's ADAS system. The surround view system developed by AdasWorks is another deep learning implementation, which processes visual data from multiple cameras and sensors in order to provide ADAS. In a slightly different case, the 2015 BMW 7 Series introduced an innovative solution that is based on deep learning technology for recognizing driver's audio commands, without the need to communicate with a central server or a cloud service. Many more deep learning applications in the automotive industry are under development, and they include fault diagnostic applications, fuel and emissions management, intrusion detection mechanisms that protect the vehicle's internal network, etc. (Falcini & Lami, 2017)

As far as it concerns hardware for the coordination of the multiple models and the data fusion among them, new high-performance applications have emerged that offer safety-related or driver assistance solutions, such as the forthcoming microchips Mobileye's EyeQ5, which will perform sensor fusion and will allow holistic vision control for supporting Autonomy Level 5 (fully autonomous) driving. The power consumption of such chips is increased, so in order to meet its performance objectives, EyeQ is designing the 5th generation of microchips using advanced VLSI process technology to the level of 7 nm FinFET.

Regarding electronic components that are already in the market, Intel introduced the Xeon Phi chip as an answer to Nvidia's Tegra chip. Nvidia's Tesla V100 is today able to perform 120 TFlops, using a total of 640 Tensor cores, which are specially designed for carrying out deep learning tasks. Nvidia also has NVidia DRIVE™ PX, for edge computing applications, which allows developing vehicles that offer many advanced AD functions. AMD offers an X86 server processor equipped with a GPU. This can be a reliable alternative to HPC and machine learning workload processing on the edge and can be a budget solution compared to Intel Xeon or Nvidia Tesla, which are already established in the market of hybrid computing. In parallel, Tesla is developing a new processor for AI applications in ADAS and automated vehicles in collaboration with AMD (Etherington, 2017). Finally, NXP offers the S32V234 vision processor, which is designed for ADAS, vehicle and industrial automation, and offers several machine learning and sensor fusion capabilities, such as front camera stream processing and object detection, surround view, etc. The processor design offers reliability, security, and functional safety (https://github.com/basicmi/AI-Chip).

## 3.3 Solution approaches for automotive eHPC platform

### 3.3.1 Overview

Apart from the evolution of microprocessors and automotive microelectronics, it is important to improve the connectivity of the embedded modules and the integrated architecture of the automotive computing platforms. Multicore processors specifically designed for real-time automotive applications along with fail-safe process for data fusion among modules and decision-making models for the interpretation of the results will guarantee operational and fully functional automotive systems in all conditions.

The combination of a real-time multicore processor specially designed for the automotive domain (e.g., with respect to power consumption, inference capabilities, speed, etc.) with general-purpose HPC processors and accelerators will allow the development of powerful data fusion platforms that can support any future automotive scenario. This embedded high-performance computing (eHPC) platform will be the basis for more applications that require security, safety and high-performance, and the automotive example will be the reference for other domains including industry, medical, and machinery (Bello, Mariani, Mubeen, & Saponara, 2018).

In the automotive scenario, various alternatives must be examined. Alternative must combine the use of the multicore architecture with the accelerators and the HPC processors, offer fast interfacing between the two, and adapt existing models, algorithms, and software architectures to this distributed processing environment. The new environment allows the implementation of various automotive application scenarios in a distributed onboard and off-board computation environment (e.g., management of traffic information can be done off-board, whereas real-time routing decisions making modules onboard can take advantage of the off-board processing results and current conditions from onboard sensors). Among the requirement for the efficient interaction between onboard and back-end off-line components will be the establishment of secure and reliable communications, the management and verification of device identity, and the privacy of data providers in collective scenarios (e.g., in traffic reporting and management applications). This implies the need for joined design and development of HW and SW and the embedding of safety and security mechanisms and processes in the automotive eHPC platform.

According to the automotive functional safety standard (ISO 26262) various levels of automotive safety integrity (ASIL) have been defined ranging from A to D, which is the highest degree of safety against hazard. In the ASIL-B level, the integrity check is based on some safety mechanisms [ECC in memory, parity in caches, CRC in network on chip (NoC)], which evaluate the proper operation of processors. In the ASIL-D level, the integrity of processors is mainly checked by performing redundant computations. The results of these computations are compared to the expected results in order to verify integrity and comparisons are performed by the safe microcontroller, which is dedicated to the task (Bello et al., 2018). The safe micro-controller monitors computations and is responsible for granting trust to the results.

As a result, the vision for the next-generation automotive platform assumes a combination of the main automotive SoC, an HPC-general purpose processor, and several attached accelerators, which are capable to control the whole perception process of an AD system. The main SoC will act as safe microcontrollers that communicate with the vehicle backend processor, which provides a run-time environment that is compliant with the Classic AUTOSAR (AUTomotive Open System ARchitecture). Two or more "safe number crunchers" will apply parallel computing and directly access sensor data through

Ethernet (camera, lidar) or LVDS (camera, radar). The main objective is thus to enhance the EPI general purpose and accelerator processor architecture, in particular, the memory hierarchy, NoC, and the computing resources, to meet the requirements of the high-integrity and the high-performance execution partitions, while ensuring freedom of interference between these partitions as mandated by the ISO 26262 functional safety standard. Other key objectives are the consolidation of the "high-performance" software environment compliant with adaptive AUTOSAR so that the integration of the sensor processing, data fusion, and deep machine learning software frameworks becomes possible.

### 3.3.2 RISC-V extensions for real-time computing

In order to support the requirements of perception tasks in automated vehicles, it is necessary to develop processes that offer real-time predictions. For this purpose, high-performance accelerators must be employed in order to guarantee high response time. The refactoring for offering time-predictability functions has to begin from the processing core, then to develop the appropriate memory structure at a local level and the interface to connect to the back-end environment, the external memory, and any other external interfaces.

Several researchers currently investigate architecture extensions to the RISC-V accelerator cores that enable time-predictability, or more specifically, the fully timing compositional property. This property states that worst-case execution times (WCETs) at the global level are composed of WCETs at the local level. It also implies that WCET of a core that has multiple resource conflicts can be safely approximated by adding all the interference times for accessing the resources to the core's WCET without interferences. The fully timing compositional property is based on the formation of a pipeline that offers in-order instructions, has a local cache and an LRU replacement policy. It is not compatible with superscalar execution or dynamic branch prediction.

Based on the directives of the "RISC-V Instruction Set Manual Volume I: User-Level ISA," that recommends the "End-of-Group bits in Prefix" approach, real-time computations can be based on a very-long instruction word (VLIW) extension of the RISC-V ISA. As opposed to superscalar execution VLIW is a core implementation technique that enables multiple instructions to be issued, and is compatible with the fully timing compositional property. The motivation is to obtain a core that has the performance of an application core (e.g., ARM Cortex-A) while ensuring the timing predictability of a real-time core (e.g., ARM Cortex-R). This approach will ensure the correct execution of any standard RISC-V binary on the VLIW core, in single-issue mode. A simple recompilation will enable the multiple-issue mode on this core. Moreover, other extensions of the RISC-V architecture defined in the scope of the EPI consortium such as vector unit will be compatible with this VLIW extension.

### 3.3.3 Monitoring and throttling capabilities of real-time flows

An interconnect is in charge of arbitrating accesses to resources that are shared among the various processing nodes, such as memory or input and output devices. The parallel requests to shared resources may invoke contentions and bottlenecks between competing processors and introduce delays to task execution over multicore or manycore architectures. When designing safety critical systems in such architectures, it is important to early detect and resolve such contentions and properly estimate the WCET of tasks. The existing approaches rely either on hardware or software in order to provide a solution to the problem. The hardware approach employs a time division multiplexing policy to avoid conflicts at runtime, whereas the software approaches use specialized execution models, such as PRedictable Execution Model to separate data access and computation thus minimizing the risk for conflicts. However, various tasks in an autonomous system may have different criticality levels, thus it is important to support mixed-criticality solutions that take advantage of multi or manycore architectures without adding the conflict risk resolution or prevention overhead at all time. In such mixed-criticality systems the noncritical tasks receive lower priority or are interrupted when conflicts reach a threshold level and gain normal priority back or relaunched when resources are released. In addition to this, several more flexible strategies that include caching or resource duplication at the connectivity level have been developed in order to maximize the throughput of multi or manycore platforms by avoiding conflicts and bottlenecks.

In the case of multicore systems, a hardware contention manager allows monitoring of the interconnect level activity. The manager improves the system's ability to allocate and de-allocate resources to critical and noncritical tasks and allows to properly schedule requests to shared resources. The result is that all critical tasks execute within the provided time-frame at the expense of maximizing the number of resource requests from noncritical tasks. In the case of manycore systems, a NoC allows the interconnection of cores. Such chips are not generic, but rather application-specific, and are designed with characteristics that fit the real-time systems they are serving. The performance evaluation of a generic NoC in handling resource conflicts between flows is still an open research topic. A routing mechanism for NoC that will monitor the competing flows and will facilitate the management of conflicts would also be in favor of manycore systems. The design of such a mechanism within a NoC interconnect is a main area of added value for manycore architectures.

### 3.3.4 Automotive eHPC software environment

Automotive software environments are structured by the AUTOSAR, which is a partnership between vehicle manufacturers, suppliers of electronics, semiconductors, and hardware and companies from the software industry that operate on a global level. The AUTOSAR developed software is quite popular among

European OEMs and is gaining in popularity in the United States, Japan, and Korea. AUTOSAR provides guidelines for the development of in-car network and communication infrastructure, defines the necessary exchange formats, and specifies an OS infrastructure for deeply embedded ECUs (AUTOSAR Classic Platform) and performance ECUs (AUTOSAR Adaptive Platform).

According to AUTOSAR, a fully compliant software environment and development kit for the automotive scenario must provide the following functionality:

The AUTOSAR Classic Platform defines the required capabilities for real-time processing and safety. The ECUs that use this Classic Platform are already deployed in ASIL-D environments. The Classic Platform together with other software parts can provide functionality that requires response times in the lower microseconds domain and safety monitoring capabilities in the performance domain.

The AUTOSAR Adaptive Platform, which is still under development, is expected to extend the classic platform and become an automotive standard for high-performance ECUs. Using the same service-oriented network protocols as the Classic platform, the adaptive platform achieves inter-operability and backward compatibility. It also is based on a service-oriented middleware and provides system health monitoring capabilities for checking the performance of ECUs, and all are available to run on POSIX PSE51 compatible OSs. Furthermore, a new standard interface that is planned to be based on the OpenCL standard from Khronos group, is defined for accessing the hardware accelerator units, thus adding to the extensibility of the platform.

The hypervisor serves a common requirement for performance ECUs that is the separation of the different software domains and processes. The use of hypervisors allows increased security and safety since it provides:

- An environment where separate software processes with varying criticalities and different ASIL can be executed.
- Secure communication with the system backend and the internet and enhances the overall security.

Since the hypervisor has full control on apps and processes, it is easy to redirect unknown or untrusted processes to virtual machines and demanding processes to separate and specialized operating systems and software stacks.

The Linux-based OS environment offers better compatibility with a wide range of software solutions, with emphasis on the HPC software and performance ECU software. The AUTOSAR Adaptive Platform is also available on Linux, thus providing more links to the Linux-based software.

The use of an SDK and interoperable data formats is expected to accelerate the software development process for the eHCP platform. AUTOSAR ARXML is the standard format for information exchange between ECUs, which is mainly based on the use of self-describing software services and components that allow to modularize the system and manage its complexity. This is very important for the near future applications that will redefine the term “system,” from a single

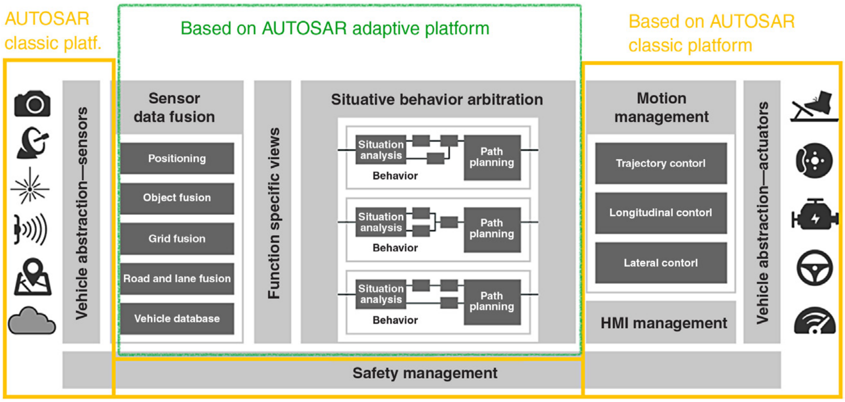


**FIGURE 3.1** **AD architecture with AUTOSAR platform.**

ECUs running on a vehicle to a complete ecosystem comprising all car modules and ECUs or even a fleet of cars that navigate in groups.

### 3.3.5 Vehicle software requirements

Inside future AD platforms, both AUTOSAR platforms work closely together taking care for basic software services and communication on eHCP (Fig. 3.1).

Several prototyping environments have been developed for supporting the implementation and testing of automated driving scenarios, such as the ROS 2.0 (Robot Operating System) from Open Source Robotics Foundation, or the EB robinos, a software development framework for AD that employs open interfaces and follows an open specification). Such environments, take the existing automotive eHPC environment for software development to another level and define the framework for future environments for the design, implementation, and testing of automated driving solutions.

Several applications that relate to data fusion, computer vision, or perception tasks, in general, must take advantage of various libraries that have been developed so far and the future software development must contribute to this direction. The optimized application libraries can be used for sensor data fusion, vehicle perception, and analysis of what-if scenarios. The processing of LIDAR sensor input requires data representation, scene segmentation, and object identification, which have to use implementations of the Point Cloud Library and Fast Library for Approximate Nearest Neighbors libraries. Similarly, high-performance computer vision can be easily achieved by processing the camera input using the functions that are already available in the OpenCV library. The same libraries can be found in the OpenVX IDE, which can be used for developing similar solutions. Sensor fusion is supported by the high-performance functions of OpenCL, or by the linear algebra libraries BLAS/BLIS and Eigen. All the above are slowly been integrated as libraries to popular deep learning frameworks such as TensorFlow or Keras, thus allowing faster development of solutions in a single, integrated, environment.

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Part II

# ITS users

Chapter 4

# User requirements and preferences for ITS

## 4.1 Requirements engineering

Requirements engineering is the first and most important activity of the software engineering process. It involves eliciting the various stakeholders needs and defines the prospective system in terms of an agreed-upon set of specifications that drive the subsequent tasks of software development (Shinde, 2017). Requirements engineering begins with the identification and specification of requirements. It continues with requirements analysis and solution development and concludes with the validation and evaluation of each requirement in order to ensure that the developed system satisfies the requirements of its users. The outcome is the specification of a clear, consistent, and complete set of requirements, and the requirements engineering guides the software developers in producing accurate software (Lawrence, Wiegers and Ebert 2001). Detailed requirements cover users' needs and drive the software development process, guaranteeing the quality of the final system that it will successfully meet users' expectations (Bano & Zowghi, 2015). The requirements also help to increase productivity and provide high-quality products (Fernández, Lochmann, Penzenstadler, & Wagner, 2011). Conversely, unclear requirements may prolong the software development life-cycle and result in defective software (Hofmann & Lehner, 2001). This shows that that requirement-engineering processes are of utmost importance in software systems development (Komi-Sirviö & Tihinen, 2003).

Nuseibeh & Easterbrook (2000) coined the term "requirements engineering" as a well-structured process for discovering the purpose for which a software system is developed and for evaluating the degree of compliance to this purpose. The process identifies the needs of the various stakeholders, records them in a form that facilitates further analysis and communication, guides the implementation process and allows for measuring the success of the software system. According to the same authors, there exist several difficulties that must be overcome, including:

- The various stakeholders (e.g., end-users, developers, paying customers, etc.) can be geographically distributed.

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- Their goals are varying and conflicting since they depend on stakeholders' perspectives of the work environment and the tasks to be accomplished by the new system.
- The difficulty to clearly define and quickly communicate these goals slows down the implementation process and further constrains their satisfaction.

## 4.2 Requirements elicitation

Because requirements engineering handles system requirements and maps them to the system development process, the elicitation of these requirements is one of the first and most critical steps of the development life-cycle. The requirement elicitation process attempts to define end-users' needs and problems, to address them and resolve them respectively and deliver a high-quality software product. Software quality depends largely on the quality of the requirements upon which it has been developed. However, the elicitation of users' requirements can be difficult, because users' needs are constantly changing, making it hard to determine, or to gather completely. In addition, many social issues can affect the elicitation process.

According to Bell & Thayer (1976), "The requirements for a system do not arise naturally; instead, they need to be engineered and be continuously reviewed and revised." It is therefore important to understand the stakeholders' needs and constraints and successfully integrate them into the system development process (Mead & Stehney, 2005). According to Kotonya & Sommerville (1998), the major phases of requirements engineering are:

- Elicitation: During this phase we find the real customer needs and record the actual requirement of the system. It also evaluates alternative solutions and examines how they can serve stakeholders in achieving their goals (Hofmann & Lehner, 2001).
- Analysis and negotiation: In this second phase, analysts identify conflicting requirements that come from different stakeholders, discuss it with each stakeholder individually, and negotiate with them in order to reach a solution without conflicts.
- Documentation: This phase includes the formal specification of all requirements, using proper requirement specification templates (e.g., IEEE software requirements specification template). The resulting document will be a guide for the remaining development stages.
- Validation: The aim of the validation phase is to ensure that the requirement specifications produced so far are free of any conflicts, omissions, or mistakes and that they cover the stakeholders' needs collected in the elicitation phase.
- Management: The last phase concerns the long-term management of requirements, which are the next steps of the software development life cycle. Since many issues may arise at later stages of the development process, it

is important to foresee maintenance activities that update the requirements when necessary. Any change must be justified and traced in order to facilitate requirements management.

In the above phases of requirements elicitation, software analysts must carefully choose the appropriate techniques from a wide-range of available techniques (Sharma & Pandey, 2013), which are described in subsequent sections. According to Hickey & Davis (2003) the selection of a specific requirements' elicitation technique for software analysts is based on several assumptions:

- The technique is the only known technique that analysts know.
- The technique worked effectively in the past and thus is expected to also work now.
- The technique intuitively seems to be effective for the current problem.
- A software development methodology is followed, which explicitly states that a particular technique must be employed.

## 4.3 Requirement elicitation techniques

Several techniques have been proposed in the literature for the elicitation of requirements.

### 4.3.1 Traditional techniques

Traditional techniques consist of interviews, surveys, and questionnaires as well as document analysis. These are the oldest and most commonly used techniques.

**1.** *Interviews*

The interviews commonly use verbal methods that require only questions to be asked by the stakeholders. They are frequently used for sharing ideas with the analysts and for expressing the stakeholders' needs. The interviewer is required to have some knowledge of the domain, social skills, and the ability to listen and record the requirements.

Interviews range from totally structured or semi-structured, that use closed questions for collecting quantitative data, to completely unstructured that use open-ended questions for understanding user expectations. Each interview type has its pros and cons, but the usefulness of the data collected by the interview is affected by the questions' quality. So, it is important to study each method carefully to choose the most appropriate to use.

**2.** *Document analysis*

The document analysis technique gathers information from the analysis of domain-related documents and can be used to form a basic set of requirements which are further refined by other techniques (e.g., through interviews). When the technique is used in a system replacement or expansion project, the input documents can be the design documents, the templates and the manuals of the previous system, which can provide rich information about current user needs.

**3.** *Surveys/questionnaires*

Questionnaires are the most affordable technique for collecting requirements. They may comprise both open and/or closed questions and can be used as a replacement for the face-to-face interaction with the stakeholders. They are ideal for collecting requirements from larger user groups and for covering large-geographical areas using their online versions. Questionnaires can be hard to change and adapt to individual needs and perceptions because they do not allow participants to ask for clarifications. They must be clearly defined and concise in order to avoid misunderstandings. Using questionnaires has several advantages, such as:

- The ability to reach a larger audience within a short time.
- The low-implementation cost.
- The ability to quantify requirements using closed questions.
- The lower bias they introduce, in comparison to the interview techniques.

Among their disadvantages are:

- The ambiguities that may arise.
- The misinterpretation of questions from the user.
- The inability to capture useful feedback, especially in the absence of open questions.
- The lack of additional clarifications from or to the user.

**4.** *Introspection*

Introspection can be the initiator of the requirements elicitation process and must be accompanied by other techniques. The analyst must be a domain expert and aware of the system's goals and the business processes that the software will support (Paetsch, Eberlein, & Maurer, 2003). The technique can be more effective when analysts and stakeholders are domain experts from all the affected fields. However, there is no guarantee that the introspection of one expert reflects the understanding of the other (Goguen & Linde, 1999) and thus more techniques must be employed to validate the initial findings.

The advantages of introspection methods are:

- Easiness of implementation.
- Low-implementation cost.
- They can be a good start for requirements elicitation.

On the other hand, the disadvantages are:

- They require that both analysts and stakeholders are aware of the domain.

- Discussions with experts and stakeholders are not foreseen at this technique.
- Even expert analysts may find it difficult to imagine every aspect of the new system.

### 4.3.2 Collaborative techniques

Collaborative techniques assume that individual stakeholders and analysts work together in order to reach common decisions. Experts from different domains contribute their opinions about the system, having equal power to the final decision. These group elicitation techniques are considered better than traditional ones, due to the multidisciplinary nature of the opinion collection process. They include—brainstorming, prototyping, and joint application development (JAD) as explained in the following.

1. *Brainstorming*

Brainstorming can be very effective in creating new ideas and extracting potential requirements. The requirements can be reviewed and filtered according to their appropriateness and importance for the system. The brainstorming process assumes recording of all ideas, elimination of those that are inappropriate, and prioritization of the remaining appropriate ones.

Brainstorming sessions require participants to:

- Generate many ideas at first, and then consider the applicability and efficiency of each one of them.
- Avoid criticizing the ideas of other participants.
- Be open about ideas that seem “crazy” at first sight.
- Build on existing ideas and expand them appropriately.

There are many advantages in the use of brainstorming for requirements elicitation. The technique can be very useful and promises great benefits, if done correctly, because:

- It is easy to learn and use.
- It is cheap to implement.
- It can generate a large number of ideas.
- It improves the working atmosphere, with the joint action.
- It motivates the creativity of participants and leads to more acceptable (at least by the team members) solutions.

2. *JAD sessions*

The joint application development methodology actively involves the end-users in software design and development, through the JAD sessions, a series of collaborative workshops, where the various stakeholders work together on the system requirements and design until they reach a consensus.

There are several benefits when using JAD for eliciting requirements, which include:

- Customer involvement and interaction with stakeholders from the very first steps, reduces delays due to disagreements and accelerates the development life cycle.
- The technique gives value to user feedback, which is part of the collaborative process.
- The collaboration increases satisfaction of users, and
- Promotes the communication between analysts and stakeholders.

The drawbacks of the technique can be:

- Waste of resources and time due to bad planning.
- Need for trained experts that will facilitate the collaborative process.
- Need for careful planning and additional effort to stay on plan.
- Increased costs for running the sessions.

**3.** *Prototyping*

The prototyping technique relies on an initial version of the product, which is rapidly launched for creating an idea of the final product and collecting user requirements. In an iterative process, the prototype is repeatedly refined, based on the user feedback. The technique can be used when the stakeholder requirements are not known in advance and an early feedback is needed (Davis, 1992). The rapid prototyping and visualization of the final software can help users to early identify the true requirements without being aware of the application or being domain experts. The advantages of prototyping are:

- Reduced cost and shorter development life cycle.
- Early detection of system problems and further reduction of the development cost (Fu, Bastani, & Yen, 2011).

Despite the benefits, there are several disadvantages such as (Mc Clendon, Regot, & Akers, 1996):

- Lack of a concrete mechanism for tracing requirements life-cycle.
- The tendency to reuse existing code fragments may keep problematic or bad-quality code until the final system version.
- It can be time consuming, especially for complex systems that require multiple refinement iterations.
- The resistance of users to change, in combination with the multiple system versions.

Prototyping is usually combined with other elicitation techniques, such as the collaborative JAD or the traditional interviews.

### 4.3.3 Contextual techniques

Contextual techniques gather requirements within the working environment (e.g., at the workplace of the end-user). The main techniques are observation, ethnography, and discourse analysis. In addition, use cases and usage scenarios can be used for getting a deeper understanding of the application context. The main purpose of the contextual requirements elicitation process is to understand the end-user work environment, when other methods fail to do so. The context must be considered at all times, since several software systems exist that have failed because they neglected the final deployment context (i.e., the workplace where the system is intended to be used) during requirements elicitation.

***1.** Observation*

Observation is a nonintrusive technique, where the requirements' engineer monitors users within their working environment. The monitoring process does not interfere with the end-users' activities. The technique is preferred when the end-user cannot properly describe the expected outcome, or when a complicated processing pipeline comprises processes that are not accessible to end-users. Observations can be passive, when the analyst simply observes without interacting with the user, or active, when the analyst asks users questions during observation. In the latter case, interviews can be used to further elucidate and clarify requirements.

The advantages of observations are:

- They are authentic and reliable, because the analyst observes what is going on in the environment.
- They can be used for confirming and validating requirements collected with other techniques.
- Their cost is low.

The limitations are:

- They may require multiple monitoring sessions to collect all requirements.
- Passive observation does not properly justify and clarify all user decisions.
- An active observation may result in different user behaviors, when it interrupts for collecting more information.
- The duration of the observation process can be long.

***2.** Ethnographic techniques*

Ethnographic studies build on the qualitative methods used by social scientists for the observation of social interactions. They monitor the interaction of culturally different groups of people over time and try to understand the social and cultural beliefs that affect end-user thoughts for the product or system and thus shape their requirements (Tiwari, Rathore, & Gupta, 2012). They are employed in the definition of contextual requirements, such as those related to usability and are preferred in collaborative work places (Zowghi & Coulin, 2005). They are usually combined with interviews or questionnaires, which provide fine-grained feedback on more specific questions that may arise.

The benefits of this method are:

- They can uncover culturally driven differences in collaborative workplaces that may affect requirement analysis and negotiation.
- They require fewer resources.
- They are useful in requirements' verification and may reveal critical issues that other techniques may lose.

On the contrary, there are several limitations that include:

- Requires expertise to conduct it.
- Focuses only on end-users.
- It is time consuming.
- It is often affected by the population diversity and fails to produce desirable results.

***3.*** *Discourse analysis*

Discourse analysis is an extension of ethnography techniques, which comprises speech act and conversation analysis. It provides tools for the systematic analysis of the interactional talk, which is a fundamental part of the requirements' elicitation process. Using various sociolinguistic methods and linguistic features to analyze discourse units and their interconnections, it allows extraction of meaning from speech, while considering the underlying social context (Alvarez, 2002).

***4.*** *Use cases/scenarios*

With use cases it is possible to describe the sequence of users' interactions with the system and identify their needs, which are mapped to the functional system requirements. The cases include fine-grained scenarios of user sessions and begin with the system status description before and after the session. They capture the user's viewpoint of requirements and are useful for creating test cases that validate them. Scenarios can be defined using natural language, but it is important to understand first the various system processes and the role of the user in them (Zowghi & Coulin, 2005).

The advantages of use cases/scenarios techniques are that:

- They do not require technical knowledge from users.
- The can help analysts to work proactively and define the target product by example.

Among their limitations is that they:

- Do not cover all the processes.

- Are difficult to be described in detail.
- Are not suitable for all project types.

### 4.3.4 Cognitive techniques

Cognitive requirements' elicitation techniques build on the much broader knowledge elicitation methods (Cooke, 1994) that allow critical collection and analysis of information. They involve in-depth problem understanding and span across multiple disciplines including psychology, business, cognitive science, etc. They comprise of card sorting, repertory grids, and laddering.

**1.** *Card sorting*

Card sorting sessions are a popular technique for collecting and prioritizing requirements. During the sessions, the various user groups are asked to sort a set of cards using various criteria. Cards correspond to domain entities and the prioritization must be done considering different criteria. The technique is more effective when all the essential domain entities are included, and requires adequate domain knowledge for producing correct results. Both analysts, who define the entities and the criteria, and stakeholders, who take the prioritization decisions, must have this domain knowledge. Collaborative techniques can be employed to improve the effectiveness of card sorting (Zowghi & Coulin, 2005).

**2.** *Repertory grids*

Similar to card sorting, the repertory grids technique requests stakeholders to evaluate specific domain entities by providing values according to various attributes. They require stakeholders to categorize entities, order the categories, and assign suitable attributes and corresponding values which are stored in a matrix. The resulting grids can be the basis for identifying similar requirements across the various domains and for locating differences between requirements. They can produce an initial elicitation that will be further refined using well-established refinement techniques (Zowghi & Coulin, 2005).

**3.** *Laddering*

Laddering is a structured-interviewing technique, which builds on the repertory grid and creates a concepts' hierarchy. It begins with the elicitation of stakeholders' goals and values and of the identification of the main attributes of the product. Working on the main product attributes it is possible to extract more information about users' criteria and preferences. The stakeholders are interviewed using different ladders each time following a hierarchy that maps the order of questions to users' priorities. It can be used in the first steps of the elicitation process for constructing the initial ladders and then integrated with a protocol editor that defines the conceptual input for laddering and further refines the ladders. Brief and concrete requirements are preferred to lengthy ones, since they can be added or removed more easily at the ladder (Shams-Ul-Arif &

Gahyyur, 2009). Although many of the earlier-mentioned elicitation techniques can be useful for requirements elicitations for intelligent transport systems, but they are not suitable because of the complexity involved in ITS.

## 4.4 Problems in ITS requirements elicitation

There are many issues that software and system designers face when they design intelligent transport systems. The design of ITS is more than simply combining telecommunication technology and information processing in novel transport solutions. The involvement of different stakeholders, including end-users, ITS managers, operators, and people that work on system maintenance increases the system complexity and makes requirements' elicitation harder. The ITS stakeholders have:

- Diverse disciplines. The stakeholders come from different engineering domains (e.g., transportation, mechanics, construction, etc.) that have varying economic profiles and follow different public policies.
- Different types of businesses areas. Stakeholders comprise public agencies such as governmental departments (e.g., department of transport) and enforcement agencies, and companies that manufacture ITS equipment or provide communication services.
- Mixed ownership and responsibilities that engage both public agencies and private companies. An example is the management of the road network that is the responsibility of the former, but is technically supported by the latter.

Designers must consider the multi-disciplinarity of the stakeholders, the different ways they work and their varying needs that drive the system objectives. So, it is necessary for all collaborators to understand and accept these objectives, and contribute to the elicitation of requirements, since the success of the requirements elicitation task has an effect on user satisfaction. A successful ITS design must address the values of all stakeholders and provide all the means for collaboration and communication of all stakeholder teams during the requirements engineering process.

The details of the application domain, the overall system context, the common work practices, and the tasks that the system must perform constitute a tacit knowledge that is difficult to be recorded and articulated with traditional requirement elicitation techniques. In order to ensure system success, it is necessary that the requirements elicitation process promote user collaboration, and involvement in all phases (Bano & Zowghi, 2015). When this is not achieved, requirements may be missed in this stage and identified in later stages of system development, thus introducing further delays to the project for code rewriting and validation. Apart from the desired system functionality, requirements also cover user expectations about the system performance as well as other qualitative attributes, which are defined as nonfunctional requirements.

Although traditional requirements' elicitation methods can deal with the functional aspects of requirements and the recording of domain knowledge, they can hardly capture the social and organizational system aspects. Organizational requirements can be captured when the emphasis is given on the social context of the system instead of its technical, procedural, or administrative aspects. The analysis of the organization's power structure, the various roles and responsibilities, the values and ethics that hold and several autonomy and control issues can help the organization requirements' elicitation (Avison & Wood-Harper, 1986). Such requirements are difficult to observe or articulate because they are deeply embedded in the structure and policies of the organization (McGrath & Uden, 2000).

The majority of requirement elicitation techniques fail to properly address the critical social (people-related) and organizational aspects of the system. The existing models do not capture "regularly-patterned" human activity (Probert, 1999) and new methodologies and tools are needed to support highly complex and dynamic situations that lead to evolving requirements. The methods must shift from fixed requirements to more dynamic ones; must consider the subjectivity of information provided by humans and be aware that the amalgam of individual, group and organizational needs is significantly different from other types of objective (e.g., physical) information. Social information is closely related to the form and activities of the organization (McGrath & Uden, 2000).

According to Hong, Chiu, & Shen (2005) *"The notion of context should be extended to different categories: computing contexts, user contexts, and physical contexts."* Since new means of interaction are established, the ITS application context becomes an essential part of activities carried out by the user with the help of the system. Traditional software design tools and methods are inadequate to support the implementation of context-aware applications and thus introduce the need for novel requirement elicitation techniques that also consider the system context. The design of contextual requirements must also consider the conflicting requirements coming from the various stakeholders.

Finally, requirements elicitation must put focus on the user experience, especially in the case of autonomous vehicles. There exist only a few studies that examine user experience expectations from autonomous vehicle users (Litman, 2017). In this case, the user experience (UX) attempts to get a deep understanding of user needs and values, as well as user abilities and limitations. Since the success of the requirement elicitation process strongly depends on the selected technique, best practices in UX requirements elicitation focus on improving the quality of user's interaction with the system, and on optimizing users' perceptions of the system and its related services (Hickey & Davis, 2003).

It is important to address many of the above problems when selecting the method to use. A new approach to elicit all types of ITS requirements is needed in order to overcome all the above limitations. The remaining sections of this chapter briefly propose an approach that can tackle all the above issues—multiple stakeholders' management, users' involvement, social and organizational issues identification, and design for context. The issue concerning users' experiences will be discussed in subsequent chapter.

## 4.5 Potential solutions for ITS requirements elicitation

The role of requirements elicitation in the development of ITS is vital and if they are not collected correctly from the beginning they will probably lead to a failure (Tsumaki & Tamai, 2006). The main reason for this is that uncaptured requirements and errors are difficult to fix at the later development stages (Sadiq, Ghafir, & Shahid, 2009). The requirements elicitation methods that are usually employed in ITS, collect the requirements from various external sources rather than from the actual end-users and thus fail to capture probably the most important application context, which is the user context. The resulting requirements do not fulfill users' expectations (Brazile, Swigger, Harrington, Harrington, & Peng, 2002). Modern requirement elicitation methodologies extend the concept of "application context" to include the user, computing and physical context of the ITS, and adapt the system development process to take advantage of this extended context notion from the very first stage. They involve real users in the requirement elicitation process and consider all possible context types in order to collect high-quality requirements that identify user needs.

## 4.6 Contextual, social, and dynamic requirements elicitation

In addition to the early engagement of users in the requirements elicitation process and the consideration of the various application contexts, modern requirement elicitation methodologies support the continuous evolution of requirements in terms of highly complex and dynamic problems such as these occurring in many ITS. The focus of these methodologies shifts from the fixed requirements to requirements that are dynamic in nature and evolve as the development progresses, or as the system begins to operate. These methodologies also assume the social aspect of requirements that emanate from user groups and organizations rather than individuals. This type of information is closely dependent on the activities and formation of the organization that employs or supports the ITS.

Since context is a driving force in the formation of requirements and the development of ITS, context awareness must be an intrinsic part of ITS development. The ITS designers and developers must consider the context in which the ITS will operate, including the environmental parameters, the expected user behavior, and the interaction of users with the environment in various scenarios, in order to better address the requirements collected in the requirement elicitation phase at later phases. ITS users are the actors and their actions are an integral part of the hosting environment, so it is important to analyze and understand context in order to provide the proper services (Winograd, Flores, & Flores, 1986). The requirements elicitation techniques, such as those based on the cultural-historical activity theory (Engeström 1987), examine the user historical activity information in order to extract activity patterns that define the user context.

## 4.7 Activity theory

### 4.7.1 Brief review of activity theory

The philosophical framework of activity theory examines different forms of human actions as development progresses that combine individual and social aspects (Kuutti, 1996). The "activity" is the minimal meaningful action that individual and/or collective actors, the "subjects," perform in order to achieve their goals. This interaction happens for a purpose, which corresponds to a fundamental need of an individual or a group. The development according to activity theory is a continuous process in which subjects (individuals or subgroups) perform activities (e.g., use methods or procedures, develop machines, and organize work) that transform objects into outcomes as illustrated in Fig. 4.1. The production of outcome motivates subjects to perform more activities (Kuutti, 1996) and this may create contradictions. Resolving contradictions helps development to go to the next stage, where new contradictions are created, thus creating an iterative development process.

Handling the relationship between objects and subjects of an activity requires a mediating tool or instrument. For example, rules are the mediating tool for the social relationship between a subject and its community. The "division of labor" mediates the relationship between the object and its community and has the allocation of tasks and responsibilities to the various roles that the subjects undertake.

As depicted in Fig. 4.2, the activities may correspond to motive, goal, and conditions and can be achieved through actions, which are further divided into operations. Actions may contribute to multiple activities and operations to multiple actions, respectively. Activities can be individual or cooperative

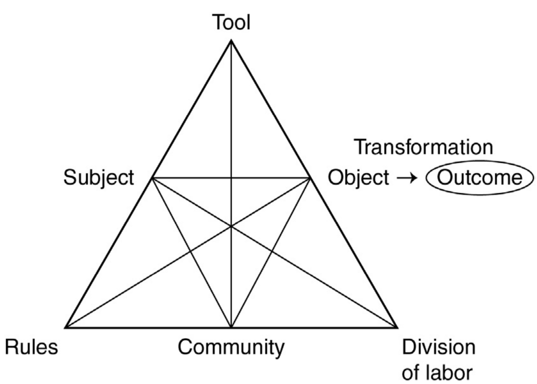


**FIGURE 4.1 The basic activity structure.**

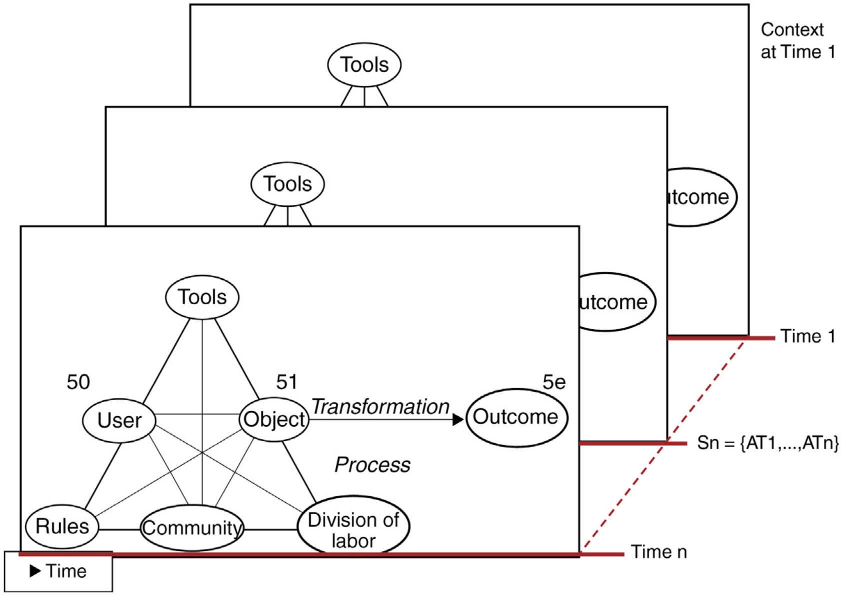


**FIGURE 4.2** **The hierarchy of activities and the respective context.**

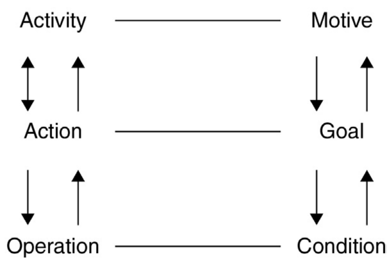


**FIGURE 4.3** **The evolution of activity theory with time.** *(Adapted from Kaenampornpan and O'Neil, 2000)*

(Kuutti, 1996) and have an internal and external component with the subject and object existing as part of a dynamic and reciprocal relationship.

The context model of Kaenampornpan & O'Neil (2004) for activities, as depicted in Fig. 4.3, captures one more vital context aspect, the time, which is missing from the basic activity structure of Fig. 4.1. This model comprises in tandem the past, current, and future aspect of the action context in order to predict a user's action from the past and current context.

Activities are not performed in isolation; they influence each other and are influenced by external activities, objects, and subjects in their context. According to Kuutti (1996), the interaction between activities or their elements may cause imbalances, which are referred as contradictions. Contradictions are described as problems, breakdowns, clashes, or ruptures that are due to a misfit between the various activities and their elements. According to activity theory, contradictions are resolved continuously during the system life-cycle and are considered a source of development. In the work of Engeström (1987) four contradiction types are defined:

- Primary contradictions refer to problems of a single activity and correspond to breakdowns in the actions of the activity. When the same action is motivated by different actors, or the same user performs different actions for different reasons or in the context of two different activities, the resulting polymotivation leads to primary contradictions.
- Secondary contradictions refer to problems in the relationship between activity nodes.
- Tertiary contradictions occur during the remodeling of activities. When the resolution of primary or secondary contradictions leads to a new, "culturally more advanced," activity that defines new practices (praxis), new objects or subjects and a new division of labor, then tertiary contradictions may happen.
- Quaternary contradictions take place when new activities replace existing activities in order to resolve primary or secondary problems. The old activities coexisted and worked in concurrency with other activities, so the new ones must resolve several tertiary contradictions and quaternary contradictions with concurrent activities (Turner & Turner, 2001).

Based on the works of Engeström (1987); Jonassen & Rohrer-Murphy (1999), Bødker (1996), Mwanza (2001), and Uden (2007), activity theory can be employed for the elicitation of ITS requirements. The steps of this requirements elicitation process comprise:

1. *Define the purpose of the activity system.*

The first step is to clarify the motives and goals of the activity system. That is to understand the context and motivations for the activity being modeled and any interpretations of perceived contradictions. Context is the activity system and the activity system is connected to other activity systems. To analyze context, we need to know the beliefs, assumptions, models, and methods commonly held by the group members, how individuals refer to their experiences in other groups, what tools they found helpful in completing their problem, etc. In addition, there are also external or community-driven contexts. It also assumes knowledge of the external (i.e., community) context, which includes (Jonassen & Rohrer-Murphy, 1999):

- Users involvved in the activities.
- Outcomes of the user's activity.
- Motive of the users.
- The limitations imposed by the environment.

- Activities and actions supported by the ITS.
- How the activities fit the users' objectives.
- Critical activities.
- Purpose of actions and activity of users.
- The structure of social interactions within an activity.
- Tasks to achieve the objective

**2.** *Analysis development of the activity system.*

This step involves defining, in depth, the components of the given activity, namely, the subject, object, community, rules, and division of labor. This study began by interpreting the various components of the activity triangle (Fig. 4.1) in terms of the situation being examined.

**3.** *Analysis of the activity structure.*

This step defines the purpose of the activity system. It involves the analysis of the activity structure including all the activities that engage the subject. Each activity is decomposed into actions and operations. The following questions can be used to analyze the activity structure:

1. How is the work done in practice?
2. How has the work evolved over time?
3. What are the different phases of the activity?
4. What is the goal of the activity and how does it relate to other goals?
5. Who performs the actions for each activity?
6. How do we analyze the operations for each action the user performs?

The analysis of the activity structure of the technology in ITS should begin with the identification of the goals of concrete actions then move to top-level actions and activities, followed by lower-level actions and operations. It is important to define:

1. The end-users of the application.
2. People involved in the design.
3. Goals for each action.
4. Limitations of the technology.
5. The conflicts between various users' goals.
6. The criteria for evaluating the system's ability to achieve user goals

ITS requirements can be captured by analyzing all the three levels of the activity hierarchy: activity, action, and operation. To do this, the hierarchical notation, which is commonly used for task analysis is recommended. (Shepherd, 2001).

**4.** *Analyze contradictions within the activity system*

It is possible to reconstruct the system by identifying the tensions and interactions foreseen between the elements of an activity system. Doing so can help us to explain contradictions and its development (Engeström, 1999). The following information can help us to identify the contradictions between the elements of an activity system.

1. The dynamics of the activity system's components.
2. The interrelationships between components of the activity system
3. Identify the contradictions between various components of the activity system.
4. The evolution of relationships over time.

### 4.7.2 Benefits of activity theory for ITS requirements elicitations

There are several advantages of using activity theory for designing ITS. First, in activity theory, individual actions are always situated in a meaningful context and are impossible to understand in isolation without the meaningful context as the unit of analysis (Kuutti, 1996). Second, applying activity theory to requirements engineering provides us with a conceptual framework that allows us to address the important issue of organizational requirements. Third, activity theory focuses on the interaction of human activity and consciousness within its relevant environmental context (Vygotsky, 1978). Fourth, activity theory describes activities as hierarchical in nature and provides a model for decomposing activities into actions and operations. However, although current research has focused on these actions and operations, it has failed to address the real intention of the user in carrying out those actions and so has failed to understand the needs of the user at a higher level. Fifth, activity theory insists that all activity is mediated by physical or mental tools. Tools affect the user and are themselves affected by the user.

A major benefit of using activity theory for requirements analysis in ITS is the resolution of conflicts. Because of the interests and needs of different stakeholders, conflicts are unavoidable. It is important to identify conflicts during requirements analysis, as this helps designers to reflect on possible design strategies accommodating all different requirements, thus fulfilling the stakeholders' objectives and supporting the needs of the users. (Uden, Valderas, & Pastor, 2008).

In this chapter, we have presented a requirements elicitation approach for ITS based on activity theory. The theoretical principles provided by activity theory can be applied in the elicitation of ITS requirements that allows us to properly consider organizational requirements that capture the cultural, cognitive, and social aspects that are related to the requirements engineering activity. Activity theory also helps us to deal with the context issues of ITS. Activity theory offers an ideal framework for the design of context-aware systems by providing guidance on what elements of context to consider. It can also support the implementation process for both user and system-driven adaptability at runtime. In addition, this approach enables us to interpret the context of user behavior in the application. Using activity theory enables us to the cover key elements of context that can influence user activity, and the explanation of how elements influence the user's ability in the actual situation.

Despite the benefits, there are limitations. To be able to use activity theory to analyze ITS requirements limitations, the designer must have a thorough knowledge of activity theory. A second limitation is the difficulty faced by analysts in unraveling activity systems and, finally, there is the difficulty of distinguishing between the levels of activity, actions, and operations. However, the benefits outweigh these limitations. Using activity theory avoids simple causal explanation of ITS design by describing it as an ensemble of multiple, systematically interacting elements, including social rules, mediating artifacts, and division of labor. It also considers the perspectives of different users and their contexts.

## Questions

1. Why is requirements engineering important for intelligent transport systems?
2. What is the best method to use for requirements engineering in intelligent transport systems?

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Chapter 5

# Co-creation of value for user experiences

Mobility is a key concern in any city. Intelligent transport system (ITS) is an indispensable component of a smart city that makes life easy for every citizen. Citizens using ITS can save time and travel easily within the city. The purpose of ITS is to achieve traffic efficiency by minimizing traffic problems. ITS provides users with information about traffic, local convenience real-time travel running information, seat availability, etc. It enables travelers to have accurate and timely information about the traffic conditions on the network, and available transport options as well as improving mobility, enhancing travel time reliability, reducing energy consumption, and promoting economic growth. Other benefits of ITS include:

- minimize pollution,
- security and safety,
- market for mobile apps,
- smart parking solutions, and
- the brain of the smart city.

Despite the potentials of ITS, the design of effective ITS is not trivial. Although technology is important in ITS, the big challenge is how to make ITS useful and understandable for people.

ITS design should involve human factor experts at an early stage of design of ITS requirements, equipment, and facilities. Effective ITS must meet users' values and experiences. A user experience (UX) cocreation of value design approach is needed.

## 5.1 Design for users

Current ITS design today tends to focus on technologies. Although technologies are important for designing ITS, we must consider UXs. If the user has a poor experience of using the system, they would not want to use it again. Today users are more sophisticated and choosier; they expect value for their experiences. The traditional approach to design lacks understanding of consumer value creation. It is important that we take a holistic approach to design effective ITS that provides a positive experience for users. To design such system requires us

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to take a crossdisciplined collaboration approach between, users, design, and technology. This chapter describes why UX should be considered when designing ITS.

If we want an effective ITS, we should shift our focus away from technology-driven ITS research and development to user-oriented design. For ITS to be successful in reducing incidence and severity of road crashes, research must be focused on developing criteria and procedures that will allow ITS human-machine interfaces to be designed and evaluated on safety performance grounds. When designing ITS applications, it is imperative that the system should provide positive UXs and enhance people's lives. We should focus on making the overall experience of the end user delightful and efficient.

### 5.1.1 Empathy

To meet the needs and values of all the users and for ITS to work, we must design for experiences. According to McDonagh (2008) empathy is defined as "the intuitive ability to identify with other people's thoughts and feelings – their motivations, emotional and mental models, values, priorities, preferences, and inner conflicts." Mattelmäki and Battarbee (2002) argued that empathy supports the design process as design considerations move "from rational and practical issues to personal experiences and private contexts." According to Koskinen et al., (2003) "empathic design," is when designers' try to get closer to the lives and experiences of (putative, potential or future) users, in order to increase the chance that the product or service designed meets the user's needs.

### 5.1.2 Experience

According to Forlizzi and Battarbee (2004), experience design research is concerned with the interactions between people and products, and the experience that results. This includes all aspects of experiencing a product such as physical, sensual, cognitive, emotional, and aesthetic. Many different disciplines such as anthropology, business, cognitive science, design, philosophy, social science, and others have developed models to help us understand experiences' theoretical approaches to help us understand experiences. These approaches are grouped as product centered, user centered, and interaction centered by Forlizzi and Battarbee (2004). Forlizzi and Battarbee (2004) gave the definitions as follows:

- Product-centered models
  - Provide straightforward applications for design practice.
  - Provide information to assist both designers and nondesigners in the process of creating products that evoke compelling experiences.
  - Describe the kinds of experiences and issues that must be considered in the design and evaluation of an artifact, service, environment, or system.
  - Often take the form of lists of topics or criteria to use as a checklist when designing

- User- centered models
  - Help designers and developers to understand the people who will use their products.
  - Integrate several disciplinary approaches to offer ways to understand people's actions, and aspects of experience that people will find relevant when interacting with a product.
  - Hassenzahl's (2003) model provides a theoretical model to describe people's goals and actions when interacting with products.
- Interaction-centered models
  - Explore the role that products serve in bridging the gap between designer and user.

## 5.2 User experience (UX)

Among human–computer interaction (HCI) practitioners, UX (UX) design is becoming a core concept. Donald Norman was amongst the first authors to use the term "UX" to describe all aspects of a person's experience with a system (Norman, Miller, & Henderson, 1995). Other definitions and models have been proposed by researchers such as Forlizzi and Ford (2000), Hassenzahl (2003), and Karapanos, Zimmerman, Forlizzi, & Martens (2010).

UX design goes beyond user interface (UI) design. 'Experiencing' is defined by Roto, Law, Vermeeren, and Hoonhout (2011) as an individual's stream of perceptions, interpretations of those perceptions, and resulting emotions during an encounter with a system. A person can experience an encounter with a system in a different way. Thus the *individual* and *dynamic* nature of experiencing the encounter with a system is important.

### 5.2.1 The difference between UX and UI design

There is often confusion between UI and UX design. Although these two are often used interchangeably, they are different. According to Stevens (2019), UI is the actual interface of a product. The visual design of the screens a user navigates through when they click when browsing a website or using a mobile app. Any interaction a user has with a product or service is referred to as UX. It is important to consider each element that shapes this experience, how it makes the user feel, and how easy it is for the user to accomplish their desired tasks when we design for UX. UX design means we are to create easy, efficient, relevant, and pleasant experiences for the user when they are using the system.

Usability is not the same as to UX. It means whether one can achieve a task or goals with a product or service. But simply being able to achieve the task of picking does not give us the whole picture of how one feels about doing it.

Ken Norton, exProduct Manager at Google, Partner at Google Ventures describes UX as the user's journey to solve a problem. UI is concerned with how a product's surfaces look and function. In the digital world, UX refers to the interactions, reactions, emotions, and perceptions while using an app, service, website, or product.UX is defined by the international organization for standardization, as “A person’s perceptions and responses resulting from the use or anticipated use of a product, system or service.” It often refers to how one feels about each interaction one has with what is in front in the moment of use. Don Norman, and Jakob Nielsen (2019) declare “UX“ encompasses all aspects of the end-user’s interaction with the company, its services, and its products.

Hassenzahl (2008), defined UX as a momentary, primarily evaluative feeling (good/bad) while interacting with a product or service. According to Law et al. (2009), UX, is dynamic, context-dependent, and subjective. He suggested that UX shifts attention from the product and materials (i.e., content, function, presentation, interaction) to humans and feelings—the subjective side of product use.

According to Hassenzahl (2003), people perceive interactive products along two different dimensions: pragmatic quality and hedonic quality. He describes “Pragmatic quality” as the product’s perceived ability to support the achievement of “do-goals,” such as “making a telephone call”. It focuses on the products’ utility and usability in relation to potential tasks.

“Hedonic quality” as defined by Hassenzahl (2003) is the product’s perceived ability to support the achievement of “be-goals,” such as ”being competent,” “being related to others,” and “being special”. It asks the question of why does someone own and use a particular product.

Hedonic quality contributes to the core of positive experience and is related to the user’s psychological well-being. On the other hand, pragmatic attributes are related to the practical usage and functions of the product that results in satisfaction. According to Fredheim (2011), satisfaction emerges if a user uses a product or service to achieve certain goals and the product or service fulfils those goals.

According to Hassenzahl (2003), “Good UX is the consequence of fulfilling the human needs for autonomy, competency, stimulation (self-oriented), relatedness, and popularity (others-oriented) through interacting with the product or service (i.e., hedonic quality).”

Nowadays, the term “experience-driven design” or “experience design” is used to describe the process of designing for UX (Hassenzahl, 2013). According to Hassenzahl (2013), the purpose of experience design is to bring the resulting experience to the fore—to design the experience before the product. Law et al. (2009) argue that UX is a subjective and dynamic concept, influenced by several contextual factors.

Robert and Lesage (2010) define the characteristics of UX as follows. First, UX is multidimensional and holistic. It has six dimensions, namely, functional, physical, perceptual, cognitive, social, and psychological, and two meta-levels are related to each of them: sense making and aesthetics. Second, UX is subjective. It partly depends on what the user brings to the interaction with the system in terms of moods, sensitivity, attitudes, prejudice, interests, knowledge, motivation, etc. as well as on the subjective emotional response to the interaction with the system. Third, UX is not static. It spans in and over time. Fourth, UX can be considered at different granularity levels. Fifth, UX is situated in a specific context. It depends on the characteristics of the context in terms of location, time, people, opportunities and constraints, technology, incidents, stakes, etc. Sixth, UX is an overall effect on the user. Finally, UX depends on four basic elements. The user interacting with a system for doing an activity in a specific context.

According to Robert and Lesage (2010), UX consist of four design elements: The user, the system, the activity, and the context. All these four elements are controlled by the design team. The users are selected by the design team who determine the type and level of user participation in the design. The system functionalities and qualities are controlled by the design team. The activity through system functionalities and related artifacts, on what the user can do with the system and how s/he does it is controlled by the design team.

The context of the system influences the design team's innovation.

The UX for any ITS should be functional, easy to use, intuitive, and delightful at every touch point. This should include the moment users start to search, chose travel options, book tickets online, or through mobile app to getting to the destination. It is therefore important for the design of ITS to understand UXs and their context if the ITS is to be successful (Buchenau & Suri 2000).

## 5.3 User experience design (UXD or UED)

User experience design (UXD or UED) is described as the process to enhance customer satisfaction and loyalty by improving the usability, ease of use, and pleasure provided in the interaction between the customer and the product. It includes all aspects of the end-user's interaction with the organization, its products and services. The user in UXD should not be treated as a distinct item. He or she is in the context of the entire system, including the user characteristics, technological objects, tools, and the environment.

The quality of UX also depends on usability. ISO (1998) refers to usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. According to Roto et al. (2011), UX is the result of the interaction between three elements: the user, the system, and the context. Many UX designers have proposed models for UX design.

### 5.3.1 The quadrant model

Stevens (2019) proposed the Quadrant Model for UX design as shown in Fig. 5.1. According to her, it can be divided up into four main disciplines: experience strategy (ExS), interaction design (IxD), user research (UR), and information architecture (IA).

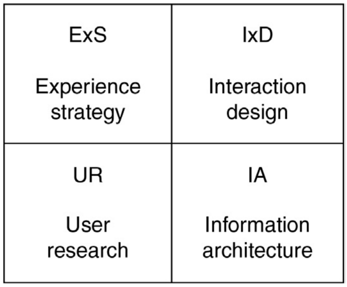


**FIGURE 5.1 The quadrant model.** *(Source: From Stevens 2019)*

1. Experience strategy (ExS)In this section, the aim is to design a holistic business strategy, including both the customer's needs and those of the company.
2. Interaction design (IxD)IxD looks at how the user interacts with a system. It considers all interactive elements such as buttons, page transitions and animations.
3. User research (UR)It is important during this phase that research is conducted to identify the problem and then design the solution. This requires the UX designer to research into potential and existing customers using surveys, interviews, usability tasting, and to create user personas in order to understand the end user's needs and objectives.
4. Information architecture (IA)During this phase, we organize information and content in a meaningful and accessible way to help the users to navigate their way around a product.

### 5.3.2 User experience design process

UXD process is an iterative method that helps designers to continuously improve and polish their designs. During the design, it is necessary to go through different stages repeatedly while evaluating the designs at each stage. Each stage must involve relevant stakeholders in the organization that take part in the process to make the products. According to Minhas (2018), the design process involves the following six stages:

1. understand,
2. research,
3. sketch,
4. design,
5. implement, and
6. evaluate.

### 5.3.3 The why, what and how of UX design

Three important questions must be considered designing for UX: why, what, and how. The "why" allows us to clarify the needs and emotions of the user in performing an activity, the meaning, the experience, and value of the users when using the product. The "what" addresses the things people can do with a product—its functionality, that is, able to provide the experience that users expected. The "how" is concerned with designing functionality in an accessible and aesthetically pleasing way.

## 5.4 Co-creation of value

In today's world, it is important that we move away from a product and firm-centric view to personalized consumer experiences in design of product and services. The reason is that today consumers are more informed, networked, and empowered. Consumers demanded cocreating value with the firm (Prahalad & Ramaswamy, 2004).

According to Gambetti and Graffigna (2010), nowadays customers, empowered by the web and the associated information technologies, want to cocreate value to build their identities, express themselves creatively, socialize with other consumers and enjoy a unique and memorable experience. Cocreation is an alternative, collaborative approach that can bring the design of ITS systems closer to their future users. It is important that we design ITS in collaboration with the end users through the cocreation of value.

The social, cultural, economic, and technological changes enable organizations, groups and individuals to interact, collaborate, and solve problems by jointly generating solutions and creating value (Chesbrough, 2011; Ramaswamy & Gouillart, 2010) known as cocreation.

According to Russo-Spena and Mele (2012), there are three research streams that stand out as starting points in the analysis of cocreation in innovation studies: the technology-driven perspective, the customer-driven perspective, and the service-driven perspective. The technology-driven perspective focuses on collaboration through an open innovation platform (Chesbrough, 2006); the customer-driven perspective emphasizes the systematic use of individuals' and communities' competences and experiences and the service-driven perspective introduces the exciting notions of value in use and the customer as value cocreator (Vargo and Lusch, 2004).

Cocreation is an active, creative, and social process, involving a set of activities based on collaboration between producers and users that is initiated by the firm to generate value for customers. According to Ramaswamy and Gouillart (2010), the idea of cocreation is to unleash the creative energy of many people, such that it transforms both their individual experience and the economics of the organization that enabled it.

In cocreation, it is important to engage, work with and empower users and designers to generate ideas and to collaboratively create concepts. The users' presence is essential in the creative process because users provide insight into what is valuable to them. Because the value of each user is different, cocreation brings together users and designers to work toward a shared goal, through collaboration, in which stakeholders, designers, and end-users explore a problem and generate solutions together by considering their different needs,

Cocreation is more than users' involvement. All actors must be actively involved in the process. All the different steps of the cocreation process must blend into the UXD. There are several benefits in using cocreation for UXD. First, cocreation helps to increase empathy among stakeholders and designers. Second, cocreation through collaborative approach promotes constructive reflection and dialogue where all parties involved are equal and working together toward a shared goal. Third, cocreation forces businesses and designers to confront the realities of customer emotions. Fourth, cocreation forces all parties to discuss the problem and solutions together. Fifth, in cocreation, designers are involved directly in uncovering requirements, they are better able to understand the reasons behind the requirements, which leads to better decision making during later design phases. There are also other benefits in cocreation for UX design. According to Verleye (2015), expected cocreation benefits for UXD are: personal benefits, economic benefits, pragmatic benefits, social benefits, hedonic benefits, and cognitive benefits.

Organizations and researchers are increasingly recognizing the importance of engaging customers in the creation of new products and services through cocreation (Payne et al., 2008; Prahalad & Ramaswamy, 2004). It is the authors' belief that the design of effective ITS should provide a positive experience to users. Thus to design ITS for UX, it is important that we apply cocreation of value in ITS design. Research from HCI such as UXs design should be used. It is necessary for us to go beyond usability design to design for UX in ITS. We should no longer be talking about ITS, but rather about the "ITS of experiences." We should focus making the overall experience of the end user delightful and efficient.

## 5.5 Design ITS user experience model

Uden (2017) has developed a model known as "Design intelligent transport systems for user experience," given as keynote talk at the 2017 ITSs—From research and development to the market uptake, *29–30 November, 2017, Helsinki, Finland*. The development of an effective ITS sheds light on the complexity involved from technical, sociotechnical, and UX perspectives. The model consists of the following steps.

### 5.5.1 Products connected with purpose

The design of ITS systems should have a positive impact on the users of the system that enhance their lives. The system should be easy to use, simple, empower the users to satisfy their needs and values.

### 5.5.2 A holistic and collaborative approach should be taken

ITS design must be approached as a whole instead of individual parts. A system engineering approach is needed. All stakeholders must work together to solve the needs and values of each party. There are many interconnected parts that are not always visible. It is important to work through each layer of the design. It is important to take a crossdiscipline collaboration between design, technology, and business. We must consider the wider context of the system. It is important to investigate carefully how ITS fits into the overall transportation network and the likes of the citizens who use it. The overall system must provide values for all the parties concerned. The author concurs with Rowland and Charlier (2015) that UX design starts with understanding the users. To understand users, we must understand which technologies are suitable for the system, the right business model to use and the service ecosystem.

### 5.5.3 Identify all stakeholders involved

The cocreation approach in designing ITS aims to serve the interests of all the stakeholders. It is imperative that we focus on stakeholders' experiences and how they interact with one another. Thus it is important to identify all stakeholders touched by the process. Having identified all the stakeholders involved, we need to understand and map out current interactions among these stakeholders.

### 5.5.4 Define user value propositions

At this stage, we must define value proposition. It is imperative we know the value proposition before we start the design. It is difficult to change once we have started the design. Value proposition is important because it is a description of what the target user will receive or realize when he or she uses the product.

Nambisan and Nambisan (2008) argued that the role of customers and their networks have changed in recent years. Instead of being a passive recipient of marketing, the customer today wants to be cocreator of the content, coinnovator, and comarketer. This means we need new business models that allow us to have a multichannel presence and increased interaction among users, and different stakeholders. Because each of these stakeholders has different values, we must consider them. To design effective ITS, we must understand the different target users involved in the system.

Many businesses do not understand their target users. They have no idea of how the users work or behave. They have no idea what the users do with their products or how they evaluate them. Customer value proposition brings together customer intelligence, competitive insight, and product valuation. It provides an aim for the designer to understand the target user in the context of the product. Customer value proposition definition must focus on users' experiences.To define customer value proposition, it is important to identify who are the intended users of the product. These are the people for whom the product is designed. The target user is not an individual. It is a segment of individuals that share the same characteristics. According to Hudadof (2009), a key target user profile should contain the following:

**Who**—who are the people using the product? (The different segments of the population, their roles and responsibilities?)
**Where**—Where are the target users located?
**What**—What are their behaviors and values when using the product?
**Why**—Why are they using the product?
**How**—How do they use the product?

### 5.5.5 Understanding user requirements

Having determined the users' value proposition, the next step is to conduct requirements design. Getting usable requirements means that we need to understand the business. Every project should begin with understanding what the product or service is meant to accomplish. We start interviewing the stakeholders in order to understand their business. It is crucial for us to establish relationships with these stakeholders as early as possible. The following questions should be asked in order to identify business requirements:

- What challenges do we face?
- Who will use it?
- Who are the important users?
- What do users need?
- What is the product?

The important thing in UX design is to identify what users want, that is, their requirements. User requirements should not be guessed. They must be gathered through user interviews, surveys, field or diary studies, etc. It is also important to gather other requirements besides user requirements. These include: technical requirements, functional, and nonfunctional requirements. The functional specifications outline what the product should be able to do. Nonfunctional specifications describe how well the product performs, such as usability, performance, data integrity, and maintenance.

### 5.5.6 Understand user mental model

Gentner and Stevens (1983) represents the structure and internal relationships of a system defined mental model as a model evolving in the mind of a user as the user is learning and interacting with a computer system. Mental models are an essential component of our world because they help shape our behavior. Norman (1986) argued that a strong or accurate mental model shows a functional or spatial similarity to the system or to the image the system presents to the users. Having the right mental model of the target users helps ITS designers to develop a more effective ITS that will provide a positive experience to the users when use. It is important to translate the user mental model to the design. There are several design approaches that help us to leverage users' mental models in creating UXs that truly address their needs. One of the approaches is to use the user personas method (Ballav, 2016).

#### *5.5.6.1 User Personas*

According to O'Connor (2011), a persona represents a cluster of users who exhibit similar behavioral patterns in their purchasing decisions, use of technology or products, customer service preferences, lifestyle choices, and the like. Behaviors, attitudes, and motivations are common to a "type" regardless of age, gender, education, and other typical demographics. Persona helps the designer to relate to people's different mindsets; to empathize with the attitudes of potential users; to understand users' context, behaviors, attitudes, needs, challenges, pain points, goals, and motivations. It also spans across demographics.

The following guidelines can be used to obtain our personas that support the stakeholders of the ITS. First, we conduct UR by asking the following questions: Who are our target users and why are they using the system? We also need to find out what are their assumptions, behavior, and expectations of the system. Second, we need to condense the research and look for themes/characteristics that are specific, relevant, and universal to the system and its users. Third. we conduct brainstorming to organize elements into persona groups that represent the target users. Fourth, the persona groups need to be combined and prioritized, they need to be separated into primary, secondary, and, if necessary, complementary categories. We should have roughly three to five personas and their identified characteristics. Fifth, we must make the personas visible by descripting each of background, motivations, and expectations.

### 5.5.7 Develop conceptual model

Churchill (2007) defined a conceptual model as a particular kind of a learning object. According to him, a conceptual model is an interactive and visual representation designed to depict a concept or several connected concepts and support conceptual learning through multimedia and processes of manipulation and interrogation of represented properties and relationships. According to Norman (1983) conceptual model is a representation of a target system designed to serve as a tool for understanding or teaching. Mayer (1989) describes a conceptual model as a representation designed for teaching and learning purposes and writes that such a representation "highlights the major objects and actions in a system as well as the causal relations among them" (p. 43).

The conceptual model is what is given to the users by the designer for the system. It is the interface of the system that users interact with. The interface of the system that designer has developed communicates the conceptual model of the product. It is important to design the right conceptual model. The reason is that if the product's conceptual model does not match the user's mental model, the user will find the product hard to use. It is important that we make sure that the conceptual model of the product that the designer developed must match as far as possible the mental model of the users. When designing the conceptual model for users of ITS, it is important to find out what are the user's expectations toward the system and his or her overall view of the system.

### 5.5.8 Cocreation of value

It is important for us to rethink regarding the design of ITS. Instead of concentrating on technologies, we must start to consider value of the users. ITS is more than a product. It is a transport service system that involves both physical and digital elements belonging to different stakeholders. The interconnection between the various stakeholders and user is complex. Because of the interconnections and networking involved, it opens new channels and opportunities for magnetization or value exchange. Today we also have the advantage of new, cloud-based opportunities, it is imperative that businesses start to rethink how they capture and create value for their users.

Value creation is the core of all businesses. It involves conducting activities that increase the value of a company's offering and encourages the customer's willingness to pay and use the system. Creating value in traditional business means identifying potential or exiting customer needs and manufacturing well-engineered solutions. For the design of effective ITS, we must understand UX. To design for UX, it is necessary for us to move away for traditional design to cocreation of value with users.

To cocreate value, we must engage the customers or users in a continuous dialogue during the cocreation process. There should a learning process where there is interaction and negotiation between the customers and the stakeholders involved. Customer experience is the primary focus, and value is a by-product of this experience. We concur with Vargo and Lusch (2004) that the experiential component of the product is essential for its actual value to be realized.

According to Plé and Cáceres (2010), we must indulge in a dialogue with customers, rather than just listening to them while using them as a productive resource during the cocreation process. We agree with these authors that the cocreation process should enable us to create an experience environment within which individual consumers can create their own unique personalized experience.

It is predicted that ITS will revolutionize the ways we live and do things. ITS enables greater connectivity in transportation and thus presents opportunities to improve our lives. Despite the potential benefits of ITS to users, however, the design of it is not trivial. Designing effective and UX in ITS presents many challenges.

Current ITS are mostly technology driven without design for UXs. For ITS to be acceptable to users, the system must be usable and intuitive. ITS should be designed for to simplify lives, enable users to carry out their tasks effectively and shape their behavior for UX. By focusing on UX, we can create products and services that meet the needs and value of the users to allow them to always have positive experience when used.

Design for UX is important. If users do not know how to interact with the ITS, they will not want to use it no matter how good the application. Experience design is to bring the resulting experience to the users before the product is produced. This requires us to cocreate value between users and designer. The cocreation of value approach can be used to design intuitive usable ITS that enhances customer satisfaction, positive experience and enjoyment.

## Questions

1. What is user experience?
2. Why is user experience important for intelligent transport systems?
3. How do we design for user experience in intelligent transport systems?

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Chapter 6

# ITS and their users: classification and behavior

## 6.1 Introduction and classifications

This section aims at classifying the users that are or will be affected by the development of ITS. A broad classification of users that are affected by ITS developments defines the following user classes:

1. Drivers
2. Road users and travelers
3. Transportation professionals
4. Regional businesses
5. Vulnerable road users (VRUs)

Users in each class have different interests, expectations, perceptions, and beliefs for ITS and the associated technologies. They examine the same problems, challenges, and solutions from different aspects and thus their opinions may vary.

## 6.2 Impact of the development of ITS on driver behavior

Driving activity can be divided into three distinct levels (Gipps, 1981; Golias,Yannis, & Antoniou, 2001; Golias, Antoniou, & Yannis, 2002a; Golias, Antoniou, & Yannis, 2002b): strategic, tactical, and operational. Operating at the strategic level is about travel planning, finding a route, etc. Tactical level includes options related to interaction with other road users, such as accepting gaps, traffic-speed selection, priority assignment, etc. Finally, the functional level includes activities related to vehicle control such as acceleration/deceleration, lane positioning, etc. The use of ITSt may affect one or more of the above levels, which are rendered with different parameters. Consequently, you should be able to (for each system) determine activity levels that are affected by the use of this specific system.

The immediate impacts are on the targeted functions of its design systemic. On the other hand, the indirect effects relate to other system effects and include driver distraction, risk compensation, enhancement risk exposure, etc. For example, the intelligent-speed adjustment system, controls the speed of the

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vehicle, compare it to a limit that is usually a little higher than the speed limit at this section, and transmits a warning signal, if the speed exceeds the limit. Consequently, the direct effects of the system are reduction in speed and increase in deceleration. Indirectly, there is effect of using the system to increase the speed to other road sections to offset its reduction, the more aggressive driving (e.g., more or more dangerous overtaking maneuvers), its large number of fluctuations speed, etc. Therefore, both direct and indirect effects should be investigated for each system (or type), so as to assess how driver behavior is influenced.

Moreover, ITS can be interconnected with the driver in three ways, that is, information systems, warning systems, and intervention systems. It has been found that the higher the degree of intervention of the system, the more effective it is in terms of their targeted operation. At the same time, different ways of interfacing result in different indirect effects such as distraction, frustration, varying degrees of compensation, etc. Finally, the type of signals transmitted can affect driving behavior. For example, acoustic signals are thought to irritate drivers more but at the same time are more effective than optical and tactile.

## 6.3 Impact of the development of ITS to travelers and road users

The first who are benefited from an ITS are the travelers (also called end-users) and the drivers (or road-users). An ITS provides drivers and travelers with increased security, rich information about their travels, shorter routes and shuttle times, easier access to parking, etc. Pedestrians and other vulnerable groups are safer and become a priority of the transportation system. The users of public transport have more travel options and rich information during their travels. Finally, the transport infrastructure is better monitored and preventively maintained, thus reducing damages and providing faster recovery in emergencies (extreme weather conditions, major accidents, etc.). The integration of ITS services has many benefits for all the groups of users, can improve the effectiveness at all cases, even in emergencies, and allow to develop advanced services that facilitate everyone.

However, in order to get these advantages users have to contribute something too. For example, in order to have correct estimations of the travel time, it is necessary to collect vehicle location and speed data. For guaranteeing driver's accountability in accidents and increase pedestrian and passengers' safety, it is required to monitor vehicles and driver's condition at any moment. On the other side, continuous monitoring may be considered a violation of driver's personal lives, or an unwarranted interference to driver's liberty. Similar issues rise around the role of driving-assistance modules in the car, that may increase driver's and passengers' safety and improve driving comfort but may decrease driver awareness. So, others are negative in sharing personal information or exchanging their anonymity with increased safety or convenience and others have no problem sacrificing control in return for improved safety and longer travel.

The users of public transport, as well as people that choose multimodal transfers perceive ITS as an undeniable asset. They acknowledge that ITS improve information, reduce travel time, improve route frequency, and reliability. Bus users are more interested on real-time information systems that provide accurate waiting-time estimations that having additional buses in the route, which are not consistent to their time schedule.

The benefits from ITS will disappear within a few years unless the individual solutions are not implemented as part of a broader plan for transportation change. The plan must combine restricted access areas for vehicles, varying pricing and priority on public transport, and city center access, etc.

Where traffic congestion reaches its limits and the need for road construction is imperative, properly designed ITS can delay such needs for a few years. The use of smart traffic signal control systems can improve travel times and streamline traffic, thus postponing the need for road construction. When conditions are right, the benefits from ITS that facilitate trip planning, automate navigation, and improve the safety of vulnerable users are more than welcome

## 6.4 Impact of the development of ITS on transportation professionals

Another group that can benefit from smart technology are the people that work in transport services, including ITS designers or administrators. The use of ITSs can significantly support their job and improve the final result. It can help them design safer and more reliable routes and public transportation means, to reduce the environmental impact from the use of private vehicles, to prioritize freight transport, urban transport, pedestrians, or any other user group at a given moment. It also allows them to manage and monitor the road network and keep a balance between the various stakeholders. The ITS professionals and designers can match the competitive needs of the residents, visitors, or shop owners of an area and at the same time protect the environment and provide safe and comfortable transport means to anyone.

ITS can help transportation planners, city administrative staff, and the government to optimize resources, plan ahead and better achieve their goals and objectives. When the traffic management plan aims to optimize traffic flow, then ITS can be used to maximize road capacity and reduce congestion. When the goal is to reduce car usage, the combination of restricted access areas and an ITS that provides transport alternatives and information on how to reduce travel time by using multimodal transport can be the solution. When the objective is to gain better insights on the usage of the road network and public transport services, then ITS can be used to collect and process large amounts of data, draw useful analytics, and make informed decisions.

## 6.5 Impact of the development of ITS on local residents and businesses

The third group of users that has many benefits from the use of ITS comprise the people that live or work on the areas covered by an ITS. The smart operation of private and commercial vehicles and the efficiency of mass-transportation services affects the quality of living, working, walking or playing, and socializing. The effects from the use of ITS services are positive for the people, the vehicles and the road network and infrastructure. Controlled access roads in residential areas are quieter and safer for children to play. The smooth flow of traffic results in reduced noise levels and fewer exhaust emissions.

On the other side, in areas that combine residential and commercial features it is important to keep a balance between the two groups, to make sure that the benefits of ITS for one of the two does not imply an unacceptable cost and a large inconvenience for the other. ITS can be beneficial for local businesses since it can reduce delivery and shipping times and increase their reliability. Visitors and tourists will increase in an area that offers multiple alternatives to reach, and can be for the benefit of local shops. The overall cost for the delivery of goods can decrease and the mobility of citizens can increase thus increasing the visibility of the local market.

## 6.6 Impact of the development of ITS on vulnerable road users (VRUs)

Another group that can have significant benefits from ITS is the VRUs. People with impairments can be supported by advanced-mobility services and user-friendly mobility design, small children and the elderly can be safer when they walk around the city and bikers can enjoy increased safety with dedicated lanes or VRU warning systems for car drivers. VRUs is still an open issue for ITS, since the number of VRU casualties is decreasing but much slower than the total number of severe and fatal accidents is decreasing, Apart from the passive safety systems that already exist in most vehicles, the protection of VRUs needs an additional behavioral change from the drivers' side and a VRU-oriented road and transportation design that prioritizes pedestrians, people with impairments and other vulnerable groups. It also needs warning systems and fully autonomous systems that aim to minimize the impact of accidents on VRUs (ERSO, 2017).

The development of ITS was for a lot of years focused on drivers, passengers, and pedestrians, whereas during the last 10 years, VRUs have started playing a significant role in the development of ITS. Several companies have been dealing with this issue, as well as the European Commission, whose directives describe the goals of ITS with regards to the protection of VRUs, summarized in the following:

- improve monitoring of findings resulting from road infrastructure safety management procedures;

- protect VRUs, while improving the diffusion of new technologies; and achieving a consistently high level of road safety for VRUs, with efficient use of limited financial resources.
- impose transparency and monitoring of infrastructure security management procedures;
- introduce a road-network assessment, a systematic, and proactive risk mapping process for assessing intrinsic road safety;
- lay down general performance requirements for road marking and road signaling to facilitate the development of collaborative, connected, and automated mobility systems for VRUs.
- establish the obligation to systematically take account of VRUs in all road safety management procedures.

Several ITS solutions that have been designed for drivers' assistance have a positive effect on the safety of VRUs, since they attack the same factors that increase the safety risk for the driver and the passengers. Such factors that impact the number and severity of car crashes and consequently the risk for vulnerable user groups include— (1) increased driving speed, (2) consumption of alcohol, (3) the inability to early notice the VRU that is in danger, and consequently (4) the slow reflexes of the driver in case of emergency (Phan et al., 2010).

Several technological solutions can provide many safety benefits for the VRUs, including among others—(1) smart speed and cruise control, (2) ignition interlock when alcohol is detected, (3) systems that detect pedestrians and VRUs in blind spots and early notify the vehicle and its Emergency Braking (EBR) system. Finally, there are many more applications that have a significant potential to improve safety and comfort including: (1) adaptive lighting and sensor systems for night vision, systems that provide blind-spot vision, cooperative warning systems for intersection safety, smart signals for pedestrian traffic, which adapt to pedestrian presence and notify vehicles at the same time.

The emphasis of ITSs in drivers, passengers, and people's safety has resulted in several applications that assist drivers in their driving tasks and consequently influence their overall behavior. The directly recognizable positive effects that relate to safety and comfort are balances in several cases from adverse effects that come from the facilitation that technology offers. For example, when the partially automated-vehicle takes control of the driving, the driver's attention and awareness decreases and this may have a negative impact on safety. Training a machine learning algorithm is usually performed in simulation environments and using prototypes and control conditions that do not always match to the conditions that drivers' face in practice, and does not provide a permanent solution, since the driver interaction with his/her environment is dynamic and evolves over time. As a result, it is important to continuously collect and analyze traffic, condition and driver's behavioral data in order to have a more accurate and updated model of driver's behavior. The large-scale collection and analysis of traffic and accident data will improve the performance of automated driving systems at all scenarios and will support the development of naturalistic, efficient, and safe ITS.

Apart from safety, which is the number one concern for ITS, comfort is another asset for ITS users, which however, is difficult to be assessed objectively. The evaluation of comfort may differ among users so few studies and applications have already tackled his problem. The existing communication interfaces of most ITS applications have been designed for young or middle-aged drivers and are rarely suitable for older drivers. Fewer ITS applications exist for pedestrians, cyclists, or impaired people and their comfort is dependent on local initiatives and regulations, if there exist any. Only a few countries consider pedestrians and VRUs as high priority users giving them their space and protection mechanisms. In such cases the role of ITS is important, since they control speed limits, they support pedestrian traffic signals and pedestrian warnings and provide controlled access to car-free areas.

## 6.7 Conclusions

This chapter has discussed on ITS users, as well as how their behavior is affected by ITS development. The analysis has shown various levels of influence on ITS users, mostly focusing on drivers, passengers, pedestrians, transport professionals and other VRUs. Last but not least, the implications of using ITS are not limited to the users of the systems, but they may also be extended to the drivers whose vehicles are not equipped with similar systems, albeit they interact with users of the systems. But as there is no in-depth research on this direction, as it is not possible to specify parameters in this direction.

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Chapter 7

# User acceptance and ethics of ITS

## 7.1 Overview of user acceptance of highly automated vehicles

It is evident that all the advances in automotive automation are quickly leading to highly autonomous vehicles that employ smart systems (e.g., cruise control, line keeping assistants, ABS, collision prevention systems, etc.) first as facilitators to the driver and gradually as active modules of a self-driving car. In parallel to this evolution that concerns a single vehicle, the advances in machine-to-machine communication and collaboration allow autonomous vehicles to operate in smaller or larger groups, to communicate with drivers, passengers, and pedestrians and gradually improve the safety, efficiency, and overall user experience of driving. This automation comes at different levels that rely upon—more, less or not at all—the engagement of the driver.

As explained in the previous chapters, the potential impact of these advances is enormous. An autonomous driving system could avoid many types of accidents that are due to driver's distraction, sleepiness, fatigue, or slow reflects and could dramatically reduce the respective fatalities (by over 90%) from those accidents (Piao et al., 2016). The technological advances can also support the development of new transport services that support multi-modality (e.g., walking, driving, and using public transportation services) and optimize connectivity between the various means of transport in order to minimize travel time and increase mass transportation. In addition, the information provided to the users of an integrated smart transportation system (e.g., traffic information, public transportation route information, safety-related warnings, etc.) will improve the driver/passenger experience and allow them to make informed decisions at each moment of their travels (Meyer, Becker, Bösch, & Axhausen, 2017; Sparrow & Howard, 2017). The development of new transportation services, and new models of traveling (e.g., car-pooling or sharing services) will transform the concept of "vehicle as a property" to "vehicle as a service," which in turn will create new business models and opportunities (Fagnant & Kockelman, 2015; Krueger, Rashidi, & Rose, 2016; Litman, 2015).

A prerequisite for the success of ITS and automated driving is the wide acceptance of the associated technologies and the advances they bring to daily life.

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For the AV technologies market to reach a critical size, where a large number of consumers (car owners) are ready to adopt the new technologies and make them part of their daily experience, it is necessary to study the factors that affect user acceptance and the beliefs and stances of people against the AV technology and ITS (Acheampong et al., 2018; Payre, Cestac, & Delhomme, 2014).

According to several studies in the field (Milakis, Van Arem, & Van Wee, 2017; Van Brummelen, O'Brien, Gruyer, & Najjaran, 2018), there are many challenges for automated and connected vehicles' technology to overcome, especially in what drivers believe about fully or partially autonomous vehicles, their interaction with them, the benefits they bring and the risks they are hiding. The challenges refer to the level of driver's awareness at each situation, and the human trust and acceptance to the automated decisions of the system in all conditions. In the first case, the need for continuous monitoring negatively affects AVs acceptance, since it decreases their main benefit that is to provide the driver with more freedom for side tasks (Merat & Lee, 2012; Pettersson & Karlsson, 2015). In the second case, the driver's role in emergency cases or in extreme conditions and the degree in which the driver supervises or takes control of the vehicle when the automated system fails or cannot operate, have not yet been defined in all scenarios (Kyriakidis et al, 2019).

The largest part of research on the acceptance of ITS from the general public refers to automated driving (Daziano, Sarrias, & Leard, 2017) and automated transport (Chowdhury & Ceder, 2016) as well as on the acceptability of driver assistance systems—in general (Adell, Várhelyi, & Nilsson, 2018; Burnett & Diels, 2018; Rahman, Lesch, Horrey, & Strawderman, 2017) or for driving under specific conditions (Larue, Rakotonirainy, Haworth, & Darvell, 2015). The results of existing surveys show that AVs are accepted to handle trivial tasks, but for hard conditions or critical tasks, they are slowly gaining public acceptance. Vehicle autonomy is not acceptable in less controlled road environments and environmental conditions, thus resulting in using lower automation levels only despite the fact that technological advances may be one step ahead. This still leaves space for future studies to explore what are the factors that influence consumers' attitudes toward autonomous driving and build on them in order to improve people's willingness to use AVs and increase their trust in their capabilities.

## 7.2 Technology *acceptance and related models*

In order to study and improve public acceptance for automated vehicles and associated technologies, several models have been proposed by transportation researchers and have been evaluated on drivers, passengers and other stakeholders. According to a US based survey that studied focus groups in three different states, California in the west, Illinois in the midwest and New Jersey in the east, (Silberg et al., 2013), drivers are positive on the use of AVs in specific driving conditions, for example, in closed motorways or in designated lanes. According to the same survey, the elder and younger population groups (above 60 and between 18 and 25 years) are most willing to pay for driver assistance systems.

A similar UK-based survey on transportation experts (Begg, 2014) shows a significant acceptance of AVs, with 28% of the participants to believe that "eyes-off" vehicles (autonomy Level 3) will be on the roads by 2040 and 25% of the participants to believe that autonomy will improve road safety. A transnational study in the United States, United Kingdom, and Australia (Schoettle & Sivak, 2014) showed that people are willing to adopt self-driving vehicles, but are still hesitant because of the high cost. The participants from the United States are mostly concerned about data privacy, the interaction of self-driving cars with normal cars and their performance in bad weather conditions. All participants were highly concerned about unoccupied self-driving vehicles and the use of self-driving in public transportation. The survey of Underwood (2014) on the 217 participants of a symposium on automated vehicles revealed several legal and regulatory barriers to the deployment of AVs, which are much harder to overcome than gaining social acceptance. The survey of Kyriakidis, Happee, and de Winteret (2015) on five thousand people from more than 100 countries indicated a higher potential acceptance for fully than for partially automated driving, since Level 5 is perceived easier than Level 3 that requires driver's attention and responsibility. Although the responders are concerned about safety and security they would be willing to pay more for fully autonomous driving and are expecting AVs to gain half of the market by 2050. The study of Payre, Cestac, and Delhomme (2014) in 400 French drivers with a positive stance against AV technology verified their high interest on fully automated driving (the two-thirds of them scored 4 out of 7 on an interest scale), but are still not ready to pay for such technology.

The crossgender study of Hohenberger, Spörrle, and Welpe (2016) revealed that men are most willing to pay and use autonomous vehicles than women and a similar study in Israel (Haboucha, Ishaq, & Shiftan, 2017) revealed that men prefer to combine autonomous vehicles with car sharing and find them a better alternative than driving private vehicles. The same study showed that a higher education level is associated with a higher acceptance of autonomous and shared vehicles.

Despite the numerous surveys and studies on the public acceptance of vehicle automation and self-driving vehicles, the real intention of consumers is not yet clear. For this reason, Osswald, et al. (2012) developed the Car Technology Acceptance Model, which is a specialization of the Unified Theory of Acceptance and Use of Technology (UTAUT) on the domain of AVs, which examines several additional concerns related to driving, such as safety and accountability. However, the effect of the model factors on the consumers' intentions to ride, buy, or drive an autonomous vehicle is not studied. The study of Madigan et al. (2016), who employed the UTAUT acceptance model to evaluate end-users' intentions toward Automated Road Transport Systems in France and Switzerland, revealed that the user expectancies for the performance, the facilitation it brings and the social influence of this technology, have a major impact on their intention to adopt it.

## 7.3 Ethical issues related to highly automated vehicles

The impressive performance of artificial intelligence and machine learning in several tasks, such as computer vision and state-space search in which they match or surpass human performance, has inflated expectations for the machines' ability to make decisions. At the same time it raised concerns about the cases where moral decisions have to be made and challenges for the ethical behavior of machines. For the moment, when self-driving vehicles detect a possible danger or a risky condition, they rely on the driver to resolve it. But even the driver that has to decide between steering the wheel in order to avoid a pedestrian and putting himself and the passengers in danger and keeping the passengers safe but putting the pedestrian in risk, can hardly be confident about his decision. In the case of a fully automated vehicle, such moral decisions must be taken automatically, thus they need humans to agree on a universal moral code. This is an almost impossible task that requires more than 2 million people to be surveyed in order to reach a valid consensus.

Although self-driving cars seem to be safer than human-driven cars in normal conditions, the difficulty still resides on the unavoidable accidents. On those accidents that still a self-driving car relies on the human to handle. In such stressful cases, that even the driver does not have enough time to respond, the fully-autonomous vehicle has to take the lead and react reasonably. Even in this case, where all the crash avoidance alternatives have been examined and the AV has to choose between two or more crash situations the autonomous vehicle has to make moral decisions, for which it is not yet been prepared. Although machine ethics already provide a moral basis for AVs (e.g., self-driving cars can break the law in order to save a life) there are still several complicated scenarios to be resolved.

The survey of Awad et al. (2018) on more than 130 countries (with at least 100 respondents each) revealed a large variety of moral principles across countries. The survey questioned drivers' decisions in 13 hard moral dilemmas that always result in someone's death. The participants had to choose between the casualties in each case: for example, between a young or an elder person, a single person or a group of people, a kid or a pregnant woman, etc. Despite the rarity of such dilemmas in a driver's life the aim of the study was to understand the variety of ethical and moral backgrounds and highlight the difficulty of setting up a universal moral code that machines would follow. A clustering of responses revealed three main groups. One that one included mostly North Americans and Europeans with a Christian religious origin and one that included East Asian population, mostly Islamic or Confucian. The last group mostly consisted of South Americans, French, and people from French colonies. It is indicative that in the scenario that sets the dilemma of choosing between the pedestrians or the passengers, people from the first group are more hesitant on putting the pedestrian in risk even if he stepped illegally in traffic. Another difference was that the first group was more preferable to choose a younger life to save instead of an older one, compared to the second group. People from countries with stronger institutions (e.g., Finland and Japan) tend to choose to sacrifice jaywalkers instead of their passengers or other drivers than people in countries with weaker institutions, (e.g., Pakistan or Nigeria). Finally, the scenarios that examined the correlation of decisions with the economic inequality of a country revealed that the decision in the case of countries with a significant economic gap inclines more toward sacrificing a poor person in order to save a rich one. Although not all the findings can be used as an input to a machine learning algorithm that takes moral decisions in the fully autonomous vehicle case, they are very interesting since they reveal the ethical variety around the world that will definitely affect the acceptance of ITS.

The problem behind such life-critical decisions is that fully AVs rely on the algorithms they run and this on the moral system that their developers programmed into them. In an attempt to begin the discussion around the moral decisions that fully automated vehicles have to make (as the National Highway Traffic Safety Administration imposed for Level-5 autonomous vehicles), Mercedes-Benz announced in 2016 that their algorithm would prioritize passenger safety, but soon took this statement back, revealing the gap that still exists in the discussion of the AV moral and ethical decisions (Shariff, Rahwan, & Bonnefon, 2016). A moral system that is not properly justified can only raise more dilemmas, which decrease trust for autonomous vehicles.

Since the decisions of an AV are dependent on the code or the machine learning models that it employs, it is important to open their logic to the public in order to increase trust. It is also important to define an accountability policy that decides on who is responsible for a bad decision that results in a deadly crash and at what degree the optimization of human casualties is acceptable. All these are subject to further research, which should also examine the possibility to personalize driving decisions so that they match the ethical and moral perceptions of the driver who will be accountable of any decision of the automated driving system.

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# Part III

# ITS business models

Chapter 8

# ITS and economic growth: investment, stakeholders, and relations

## 8.1 Introductory definitions related to economic growth

Looking at the existing literature worldwide, one will notice that the term "economic growth" or otherwise "growth" is a very complex concept and can be difficult to define and analyze. The term growth in finance refers to the growth of the real production of products and services in an economy over time.

By definition, the measure or indicator of growth is the long-term medium percentage growth of the real gross domestic product (GDP). The index is calculated in real terms, that is, inflation-adjusted, and not in nominal terms. Growth refers to the long-term trend (decades and centuries) and not in the short-run (quarters, semesters, and years) of the output of the product.

Economic growth is an important area of macroeconomic study. One of the most valid theories that have been developed in this regard is the Solow-Swan model (Solow, 1956; Swan, 1956). This model quantifies long-term growth as a product of four factors:

1. Production,
2. Gross domestic product,
3. Growth population, and
4. Personal income.

Nevertheless, several researchers include also technological development and other factors in the economic-growth equation. To avoid confusion in terminology, most economists use the term "growth" in conjunction with the English term economic growth and the term "development" in conjunction with the English term development economics. In this more accurate sense, economic growth is the long-term GDP growth rate, while growth is defined as the growth—at some point—of the prosperity enjoyed by the people of a country. The most important indicator of growth is the long-term growth rate of GDP per capita, while other indicators are also widely used, such as indicators related to the level of health, education, and longevity. However, when a country's population tends to remain balanced in size in a period of time then economic growth and growth do not differ.

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In any case it is noted that both economic growth and growth refer to really deflated amounts, that is to say, increase in quantity and quality of the products and services provided. In this respect, the nominal development and/or growth are related to the increase in the prices of products and factors of production.

According to the European Commission (SC) studies on urban economic development (https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development_en, September 2019), it is understandable that the term economic growth is a broad field with different meanings for different people and in general economists are working to boost the economic activity of a region, while aiming to create more jobs, to generate wealth, to create a stable-tax base and improve the quality of life of the people there (at continuous rather than temporary basis). This area can be a neighborhood, a city, a region or an entire state/country. The basic definitions used in economic development studies explain how the effects of economic growth are related to broader issues of a community, such as:

- Social impact: Includes all types of benefits and disadvantages that are of value to society, including all the impact types below.
- Impact of transport systems: defined as impacts on the value of the travel time of travel costs and security. They include both the financial implications (such as travel expenses, corporate expenses due to delays, etc., as well as non-monetary expenses (such as the value of personal time lost due to a delay).
- Impacts of economic growth, defined at the level of the economic activity of a given region. This includes position changes labor, wages, and business production.
- Environmental impacts: include impacts on air pollution, noise generated, quality of life. These impacts are "intangible" but can also be expressed in units of money.

Even if transport infrastructure and related-activities are traditionally considered as one of the pillars of a growing economy, the investment on transport infrastructure must be balanced between urban and nonurban areas, must examine what is critical for the development and what can be actually funded and must take into account the technological landscape at world level. All these are questions that require scientific research, evaluation of solutions and proper planning in order to lead to a successful and sustainable transport system. Sustainability is an important concern since the rise in the use of alternative energy sources, the recent information and telecommunication advances and the popularity of artificial intelligence set new challenges for the next generation of ITS (Agarwal and Alam, 2018).

Although scientific research unanimously accepts such advances, it is important for the national economies to evaluate the available solutions and carefully combine them in an operational and profitable ecosystem. Since the transport sector is one of the foundations of modern society that depends in tandem on geographical, demographic, political, economic, social, and technological factors, it is important to consider them jointly and plan the most appropriate solution per case. This task requires a complete intervention that comprises the planning, implementation, and evaluation of various transports infrastructure modules and their smooth integration and operation optimization. The benefit from this is directly visible since transport holds a large chunk of the gross domestic product pie of each country. As a result, any attempt to bring transportation forward and improving the respective infrastructure and services has fruitful results on the national economy.

Many believe that improving the transport infrastructure in a country incurs the construction of new roads or the reconstruction of existing ones. However, the future of infrastructure is based on the implementation of new technological systems in collaboration with conventional infrastructure projects. New sensor systems, recording base stations, processing, and information will govern the new transport infrastructures in modern societies. In fact, transport systems mainly refer to networks, and the importance of networks lies behind the information they contain. This information should reach out to infrastructure users by providing them with the means to improve the timing of their journey, its quality, and so on, reducing its cost of implementation.

Tourism is another area that will benefit from the implementation of ITS in a country. Essentially, through facilitating the accessibility and provision of information on how to best travel internationally and nationally, travel times and schedules can be improved, comfort levels can be increased and safety during public transport can also be enhanced. The analysis of the benefits from the application of ITS-related technologies in an area shows that apart from people mobility will be beneficial for freight too and will make a country even more competitive in the field of transport worldwide. This will create new financial resources and will ultimately increase the national GDP and income. Also, due to the reduction in the times of movement of goods and services, prices can be reduced, which is very encouraging of the prevailing inflation.

## 8.2 Investments in ITS

There are various ways of assessing the impact of investment in ITS on economic development. Some of them are listed below and range from theoretical research to simulation and small-scale applied case studies.

- Assessment through polls and online surveys that target domain experts and economists.
- Benefit-cost analysis of the investment.
- Cost-effective analysis.
- Multi-factor analysis.
- Evaluation of small-scale case studies.
- Development of input-output models.
- Development and simulation of dynamic models for various scenarios.

Zhicai, Jianping, & McDonald (2006) compared the cost-benefit analysis with the cost-effectiveness study and other multifactor approaches to evaluate the correlation or differentiation between the advantages and costs of investing in ITS over a specific length of time. They concluded that while cost-benefit analysis remains dominant in the evaluation of apps related to transportation, cost-effectiveness analysis, and (even more) multicriteria analysis could be useful when it is hard to quantify the benefits and provide quantified results in monetary terms. They also stressed that existing investment valuation procedure in ITS are readily suitable for assessing several impacts of ITSs.

Efforts should therefore be made to develop evaluation methods for investment in ITS that have the same form and level of complexity as that of evaluation of conventional transport infrastructure projects. The research of Hardy, Gao, & Farooq (2005) on the evaluation of economic impacts from the implementation of ITS in the area of Michigan area used the method of input-output models. The researchers tried to quantify the impact that ITS will have on various economy domains in the Michigan area with two different software packages. They also tried to quantify the benefits of saving time and fuel, using the total cost-reduction factor to calculate multipliers for each economic factor separately. Their study agreed with the results of several more research studies (Djordjevic and Krmac, 2016; Yan, Zhang, & Wu, 2012; Fei, 2010), which concluded that almost all financial and social factors are increasing after the implementation of ITS solutions. Let it also be noted that methods of estimating investment in transport often do not focus on ITS, however reading is useful, as they offer a broader approach to the subject.

## 8.3 ITS investments planning

The investment in ITS has to be performed in three major stages that go from the conception to the implementation of the investment. In the first stage, it is important to define the vision and objectives behind an investment in ITS. The objectives must be realistic and account for all the factors that affect ITS success.

The second stage refers to the development of a suitable framework for the design, implementation, and adoption of ITS. The framework must define the overall ITS architecture, the required infrastructure modifications/amendments or new investments and the list of ITS services that will be delivered. It is important to take into account the perspectives of the three main stakeholders' of ITS which are the system users, the system operators, and all other third parties that participate in the development and exploitation of the ITS. Because of the different conditions that hold in various regions of a national transportation network, it is impossible to deploy the exact same ITS services and probably modifications and customizations are needed in order for an ITS service to be deployed nationally, for example in the entire national road network. In order to accelerate the service deployment, it is important to cluster together parts of the network that expose the same characteristics (road types, socio-economic features of the region, etc.). Then, it will be possible to deploy the same ITS services for each road group and use representative parts to test and pilot the deployment of each ITS model.

The last stage of the investment concerns the deployment of services and the integration with existing infrastructure and services, the operation of the new ITS services, and their long-term maintenance. In order to guarantee proper deployment and sustainable operation of ITS services, it is necessary to define a clear implementation plan for the investment. The plan must comprise a process for the systematic feasibility evaluation of any ITS solution and must be supported by a group of organizations that will allow overcoming potential obstacles and barriers that may rise during the ITS implementation and setup.

The benefit-cost analysis is a tool that can be useful for studying the feasibility of any ITS solution. Based on this analysis, and given that the investment plan is approved it would be useful to form an international board of experts that will coordinate the plan development, will resolve any financial and organizational difficulties, will monitor the development of ITS infrastructure and guarantee compliance to existing standards. The international character of the board will add to the plan implementation, especially when the original plan and the design of the system architecture step on existing good practices and successful investments on ITS. Since success in a country does not necessarily imply success in all other countries it is important to stand on best practices and also consider the results of the socio-economic analysis from the first stage. This will allow a better adaptation to the country's special requirements and its socio-economic standards. In a similar manner, ITS projects that failed in a country may succeed in another country, so the various technological, socioeconomic, and financial aspects that determine the best deployment options for ITS services have to be considered in order to turn them to successful projects. and deployment options. Surveys that collect and analyze such background information are useful tools in this direction.

In order to better plan an ITS investment, it is important to study the aspects that may affect the final result. This includes the interoperability of the developed ITS services, their ability to be expanded or replace one another (interchangeability) and the ability to seamlessly connect all services in a common infrastructure. A successful ITS investment plan must adequately address the following issues that may delay the design and implementation process:

- Define the communication protocols and the various technology standards that will cover all aspects of the project.
- Run pilot projects on prototype installation that will early highlight risks and caveats and will allow testing the ITS performance.
- Select a unified infrastructure for installing the model ITS and all its subsystems.
- Properly define the organizational structure and the responsibilities of the staff during the development of the system.

- Consider the maintenance, upgrade, and renovation of existing infrastructure during the system planning.
- Clarify legal and ethical issues related to data protection and privacy, as well as to data usage and operational interoperability
- Establish the technical framework and the necessary services for data exchange between the traffic management centers and end-users or external stakeholders.
- Determine the general framework for ITS service modeling, using common practices at all levels.

## 8.4 Stakeholders, relations, and strategies

In order for an investment in ITS to succeed it is important to gain a complete understanding of the requirements of every possible stakeholder group. Since the groups of stakeholders may differ between the various ITS services it is important first to identify the stakeholders that are engaged in each application scenario from the first stage of the investment plan. The proper definition of objectives, roles, and responsibilities has to be defined from the beginning and be considered in all the remaining stages of deployment and operation. This preprocessing will allow preventing any conflicts between stakeholders and achieve the development and exploitation of the solution at a faster pace.

For example, in the case of ITS investments on road networks, a broad classification of stakeholders may comprise—(1) network users, (2) network users, and (3) third-party beneficiaries that either provide, operate or use the ITS services. The group of road-network operators comprises all the national or local authorities that control and operate the road network, as well as several road construction companies that are actively engaged in the development of the transport network. It also includes agencies that are responsible for traffic monitoring and management. The group of road network users comprises both individual drivers and passengers, as well as professional drivers (e.g., bus or freight drivers). The users are mainly interested in information services (e.g., for traffic, accidents, etc.) but soon will require more advanced services that relate to autonomous driving (e.g., car-platooning services, V2I-communication services that prevent accidents, etc.). Third party companies are usually not directly related to the construction or transportation industry, but their business interests are indirectly linked to the smooth operation of the road network or requirements for a successful ITS solution (e.g., telecommunication or IT-service providers).

In order to run a successful investment plan in ITS, it is necessary to consider all the underlying social, economic, geographic, and political conditions that hold at any moment and can affect the deployment and operation of ITS. A complete investment strategy for ITS at a national level must also carefully examine:

- The differences that may apply between different regions in the quality of the road network and in the financial ability of local governments to support the investment.

- The ability to support free-transportation operations among neighboring areas.
- The frequency of natural disasters in specific areas.
- The size and capacity of the national road-network operator, if it is a single one, or the ability of multiple operators to collaborate and coordinate actions.
- The existence of widely accepted standards and frameworks for the design, development, and operation of ITS.

## 8.5 Barriers

The biggest problem that one has to face when they want to develop their own model for assessing the social and economic impacts of the implementation of the ITS in a society, it is that every society and every region has its own unique economic and physical characteristics. This implies that any bibliographical references have been using financial models that depend on the particular characteristics of each region. In addition, such surveys are usually conducted at a national level and this means that each country uses its own software and financial models that are not available to the general public for investigation.

Moreover, as new ITS technologies often open completely new markets in the transport sector, ITS has the potential to have great impact, as discussed earlier, in a number of areas. However, in order to achieve these impacts on a Pan-European level, the regulatory, market and cultural/attitudinal barriers need to be overcome, such as:

1. The regulatory and financial (e.g., insurance) boundary conditions for higher levels of automation that are often associated with next generation ITS are under strong discussion and evolution, presenting a big fragmentation at Member State level, and will naturally impact the market for the enabling technology.
2. ITS technologies will be successful on the market only with appropriate customer acceptance and trust.
3. The identified risk for achieving the public-cost savings in maintenance contracting, road inspections, and surveillance are strongly connected to contract terms set by each of the bodies executing procurement.

## 8.6 Conclusions

The analysis above indicates the importance of exploring the impact of investment on ITS in an economy. It becomes clear that the differentiation of the search methods according to the application area and the data available is crucial for the results to which a researcher can be led.

It also recognizes the importance of quantifying the impact on the economy from the ITS implementation viewpoint. Evaluating such investments is a tool in the hands of the leadership of each country as a decision-maker, they cost a lot, but will yield in the long run.

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Chapter 9

# Impact of ITS advances on the industry

## 9.1 Introduction

According to the forecast of Grand View Research for the ITS Market for the period 2019–25 (Grand View Research, 2019), the value of the global market is expected to have an average growth rate of 10.5% on its 2018 value of 25.5 million US dollars. With the main requirement being the delivery of information to drivers and passengers, for safety and smart mobility reasons, companies and organizations have invested millions in V2V and V2I communication systems, as well as in smart technologies that can be on-board of vehicles. According to the same study, the use of the public transport system is also expected to grow, Europe, and North America will increase safety regulations and Asia Pacific will have major government investments on ITS.

Key players from around the world are putting forces to stand ahead in the competitive market and contribute with novel systems for ticketing and parking management, for traffic supervision and management, for vehicle autonomy and safety. All these novelties consequently affect the automotive industry, which aims in better vehicles that support the advances, and indirectly the semiconductor industry that is the pillar where automation, sensors, and actuators, smart and embedded systems are standing. The effect in the ITS industry overall is significant, starting from hardware and moving on software and communications, which in essence leads to a major digitization step.

## 9.2 Increasing levels of human-centered automation in ITS will drive the worldwide economy

No doubt, the next steps in different industrial domains will be toward higher automation levels, where machines take increasing responsibilities and nevertheless seamlessly collaborate with humans. This holds true in future industrial production systems (e.g., collaborative robots), in healthcare (e.g., assistance robots), and especially in the ITS domain (Fig. 9.1). In the latter, the roadmap toward full automation (SAE Level 4) and autonomous driving (SAE Level 5) are quite detailed.

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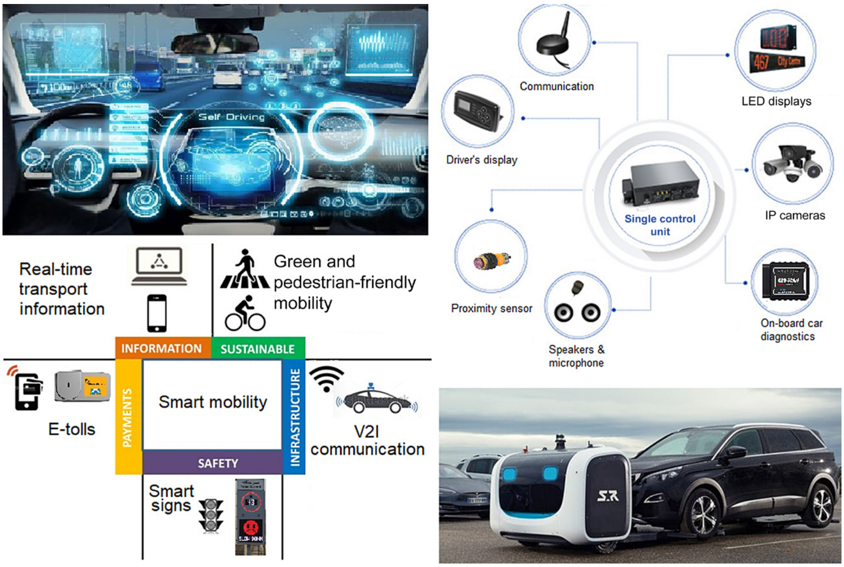


**FIGURE 9.1 Crosssectional application of ITS innovations.**

Recent ITS research efforts focus on the application of innovative techniques for highly automated driving. Nevertheless, it is to be mentioned that these innovations can be transferred to other industrial domains. Higher level of automation represents a three-dimensional challenge—organizational, functional, and cyber-physical (Fig. 9.2). The speed of change is often limited by the organization "value chains" that create, manufacture, and service the systems and products.

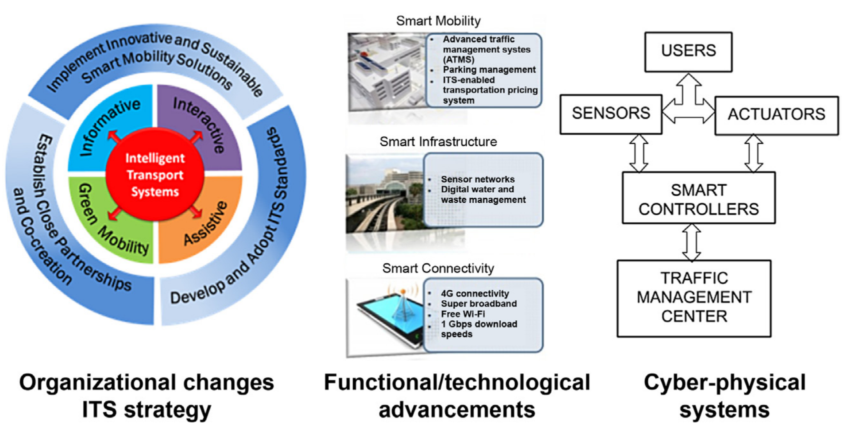


**FIGURE 9.2 A challenge in three dimensions.**

## 9.3 Evolution of safety and reliability requirements with increasing automation

Safety, reliability, robustness and availability requirements evolve toward automated and autonomous driving. Further, users will only accept and buy automated vehicles, when they trust the technology. Therefore ITS puts focus on features that allow making decisions more like humans, that is, by including cognitive skills, by applying human-centered artificial intelligence (AI), by non-causal reasoning on safe and reliable platforms of cost-efficient vehicles. We see this as a prerequisite to widely open the future market of automated and autonomous driving.

Despite the many required advances compared to the technical and technological state of the art, the ITS presuppose that the connected and automated vehicle will come: There are many reasons and use cases for this confidence, as indicated in Fig. 9.3 in view of connected cars, and in Fig. 9.4 in view of automated vehicles. No doubt, the highest benefits for society are given by a combination of automated and connected vehicles with electrification. Meanwhile, in addition to the automotive and their supplier industries, there are new players, for example Waymo, working on automated, even autonomous vehicles. Due to the strong importance of the automotive industry for Europe, additional endeavors are needed to keep pace with the US and Asian competition. Using cutting-edge technologies, ITS is striving to achieve real progress toward efficient, well-performing, safe, and reliable automation that is available also in critical situations, thus to earn the benefits of automation listed in Fig. 9.4.

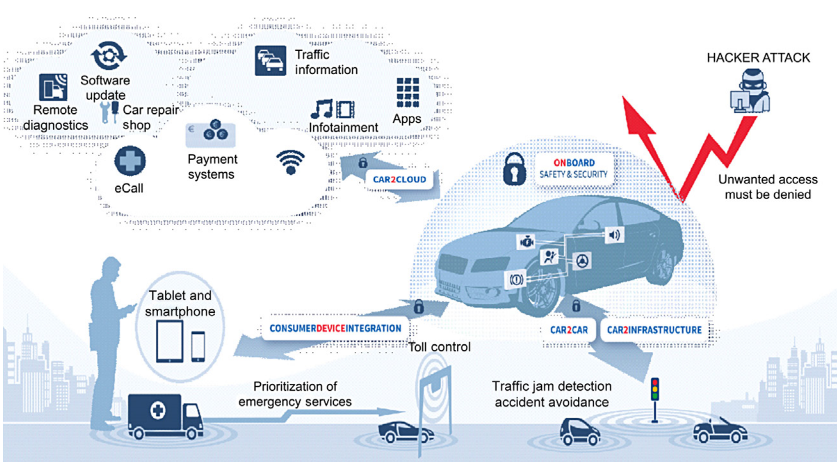


**FIGURE 9.3 Reasons and use cases for connected vehicles.**


**FIGURE 9.4** **Advantages and use cases for automated vehicles as a subset of ITS.**

## 9.4 ITS key targets to strengthen European and worldwide industry and its competitiveness

ITS are associated with key industries in Europe and worldwide—the automotive industry with highly efficient automated driving and the manufacturing industries with highly automated decision processes. On the meta-level the building blocks for both applications can effectively be assigned to three layers:

on the bottom, there is the "drive" layer including motors and engine, transmission, braking, steering, and suspension (automotive)/or the processing layer (industry);

the middle layer "environment sensing" is composed of on-board sensors (e.g., ultrasonic, LiDAR, radar and camera sensors, GPS, digital maps), connectivity (DSRC, WiFi, and cellular network) and data fusion (sensor data, central computing)/or the quality inspection in industrial manufacturing by inspection, measurements, etc.;

on top, we find the "decision making" layer, which hosts software for decision making and the HMI to the driver/or in the industrial case the quality approval.

## 9.5 Artificial intelligence (AI) is the basis for cognitive, human-centered ITS

The European position in research, development, and application of cognitive and AI has fallen behind the United States and China. One sobering and alarming indicator is a look at the publication figures of the recent AAAI Conference on AI (Kopf, 2018). The United States alone is responsible for more than one-third of the publications closely followed by China that has nearly a quarter. European countries like France, Germany, and Italy are at a mere 2% each. Together, the European countries dropped from second place in 2012 with 19%

of all publications behind the United States (41%) and before China (10%) to only 13% and third place only 5 years later. Over these 5 years, China more than doubled its contributions (from 10% to 23%) to this main research venue in AI. The entire European research output published in the prime conference on AI has by now reached an alarmingly low level.

The investments made in China in AI over the last 5 years have put them into a position rivaling the United States, leaving Europe far behind. Besides the academic dimension, there are many indicators that there is an arms race for dominance in AI, with China investing heavily and continuously. Other countries including Russia, Japan, India, and South Korea have realized the importance of the field and have prioritized research moving AI forward.

In Europe, individual states and regions are investing in AI and are setting up programs to support research and development efforts. Many realize that an initiative is required. Many companies and institutions try to set up AI research and competence centers. However, in order to be competitive on a global scale, European effort is required. The regional and national efforts are generally targeted at enabling local companies to use AI, rather than moving AI itself forward.

In contrast, China is pushing for leadership in this area by 2030, with the Chinese government to announce the first major investment plan on an AI industrial park that will cost 2.1 billion USD (Cyranoski, 2018). Companies providing solutions in the area of AI are currently mostly found in the United States. Companies like Google, IBM, and Microsoft are offering cloud-based solutions for machine learning and AI. Such services include image recognition, text understanding, conversational systems, emotion detection, and more general big data analytics. Such services are extensions to conventional cloud services and are provided such that little experience is required to use them. This makes the application of AI simple, but at the same time requires to collaborate on nearly any modern and meaningful product with US companies and to share revenue with them.

Also commonly used libraries are developed and provided by companies from the United States. One prime example is TensorFlow, the open-source machine learning and AI library, which has been developed by Google's ITS Team. The efforts put in by Google, Microsoft, and IBM (and many others) and the results that are achieved are just amazing, for example, from an AI that plays GO better than any human to systems that have machine perception on a stunning level. Without a large and coordinated effort, it seems impossible to imagine to rival these technologies or to even just create technologies that are comparable in quality. The big software companies and also Amazon have moved into the AI field to extend their business models and to force a tighter integration with their customers and their other products. European companies make use of these AI services provided by US companies, as there is a clear need for these technologies and as they are not able to develop them in-house or to get them in Europe.

It is foreseeable that for many companies operating in more traditional business models, for example the automotive industry, logistics, manufacturing, and financial industries, AI will become a key success factor. Companies like Uber or Tesla, active in providing mobility, and Amazon in the area of logistics and personal assistance, invest strongly in AI as they see an opportunity to revolutionize the way they provide services to their customers. Here, too, the key players are currently in the United States, ranging from IT companies such as Google, Microsoft, and Apple to services providers such as Uber and Amazon.

At the same time, a significant part of the talent working in AI is educated in Europe and has its origins in Europe. Many graduates in computer science, machine learning, computer vision, math, and statistics get an excellent foundation at Universities across Europe on BSc, MSc, and PhD level. They are equipped with excellent skills to work in the area of AI, do research in machine learning, and create new intelligent systems. With little exciting research and development efforts in Europe and a few of the driving companies in Europe, there is a significant ITS drain. Many of the best students move after completing their degrees to work with companies such as Google, Microsoft, Amazon, Tesla, Apple, or Facebook on challenging AI problems in environments where AI is moved forward and not just applied.

In order to make Europe more attractive as a place to conduct research in AI, ITS needs to cater for the creation of an exciting research environment that is well linked to major companies. Such concerted European activity, if successful, has the clear potential not only to keep top talent in Europe but to even attract the best international students to come to Europe to do research and found new companies in the vicinity of where they find the best research.

## 9.6 Generating user acceptance by functional-safe algorithms and methodologies for ITS

User acceptance is essential for the successful implementation and later exploitation of any automated system. This holds true in particular for highly automated and autonomous driving as well as for the new, environment-friendly propulsion systems. In the case of autonomous vehicles, user acceptance mainly resides on the increase of driver's trust toward the self-driving automation. Trust can first be achieved through extensive testing that can be verifiable and understandable by the user. It can also be established through the good performance of the vehicle over time, which must ensure driver's and passengers' safety and comfort in all conditions that the self-driving module is active. Finally, in order to maximize the acceptance of each individual driver, it is also helpful to provide personalized systems that adapt to individual driving behaviors. It is important to understand that when the driving responsibility passes from the driver to the vehicle controller and the decisions differ significantly from those of the driver, the result can be user disappointment and disapproval of the technology.

Since autonomous driving systems use AI algorithms for predicting forthcoming situations and make better decision making, it is important that as many situations as possible have been used at training time and that the deployed technology guarantees continuous learning, not only from a single user but from all the users of this technology (Shalev-Shwartz, Shammah, & Shashua, 2016). The correct estimation of the behaviors of surrounding vehicles will provide the autonomous vehicle controller the information needed to understand the situation better, act preventively and provide a smoother and more comfortable reaction in case of an incident. It can also help in reducing energy consumption by avoiding unnecessary throttling.

In the case of intelligent multimodal transportation and smart mobility in the context of smart cities, the ITS must guarantee informed and justified decisions and gradually prove to the users that all the recommendations help them in gaining time or reaching their destinations in a convenient manner. These directly noticeable advantages will increase people's trust and will accelerate user acceptance.

Future vehicles will have multiple energy sources and sinks for propulsion. These need to form a multi-redundant, safe, and reliable systems. Requirements increase even more with the integration of cognitive intelligence: In order to behave like a human-driven vehicle, future automated vehicles will need to "look ahead" not just for potential obstacles, but also on weather, terrain, and other parameters. In this context, information from external of the vehicle is to be integrated, requiring safe and secure communication. Of course, all need to be realized in a cost- and power-efficient way. We must not need several kilowatts of power just to run the signal processing of an automated vehicle. To handle all these requirements, ITS puts emphasis on the development of AI-optimized hardware (also called silicon-born AI) and on the realization of powerful, safe, reliable, and secure hardware platforms.

In terms of the underlying technology and the manufacturers behind them, AI has attracted interest from every corner of the technology world. This has ranged from graphical processor unit (GPU) and CPU companies to FPGA firms, custom ASIC markers, and more. There is a need for inference at the edge, inference at the cloud, and training in the cloud—AI processing at every level, served by a variety of processors. The importance of embedded hardware and mainly microprocessors is obvious for the AI-powered vehicles' industry. Since the continuous training of machine learning models relies on the fast processing of heterogeneous data and requires significant computing power, the leading tech companies and AI research institutions invest lots of money in researching for high-performance processors that can handle the large computation load at the edge, thus avoiding bandwidth consumption and processing bottleneck on the cloud. Typical examples are:

- The deployment of low-energy consumption, but powerful, GPUs, which can be embedded in autonomous vehicles. NVidia, a major graphics hardware accelerator developer, is currently developing AI accelerator chips that can be embedded on autonomy-level five vehicles that can process camera and other sensor input data and employ pretrained models in order to take decisions in real time.

- The design of AI computation specific hardware that can further accelerate data processing partially "at the edge" and partially "at the cloud" in a transparent manner to the end-user. Cloud service providers such as Google and Amazon hardware divisions are working on AI accelerator chips and architectures such as the tensor processing unit (TPU). TPU is AI chip that offers 15–30 times computations than GPU's using 30–80 times less power.

The transparent processing of data, both at the edge and on the cloud is expected to explode in the next few years, with investments on micro-chips to reach 6.5 billion USD by 2021 and the respective investment on machine learning-based knowledge inference going from zero to 1 billion USD each for data centers and edge devices per year (Morgan, 2018). The rise is estimated to be higher for edge devices than for the data centers, which will undertake all the inference workload leaving training—which is, in essence, the preprocessing—for the cloud backend.

In this same direction, Tesla has recently announced, at the Tesla Autonomy Day event, its new full self-driving (FSD) chip (Pell, 2019). Manufactured by Samsung in Austin, TX, the custom chip, says the company, was built with autonomy and safety in mind and is currently shipping in its new models, including S, X, and 3. The 260-mm two chip, features a pair of neural network processing modules that can handle 36 trillion operations per second (TOPS) each with a power consumption of 72 W. Two such chips will be installed on each of the company's FSD computer boards, delivering 144 TOPS for collecting and processing data from radars, cameras, and ultrasonic sensors, using the embedded deep neural network architecture. The company is claiming "FSD" capability at the hardware level, for all the vehicles that are equipped with these chips. For that, says Tesla founder and CEO Elon Musk, "All you need to do is improve the software."

According to the Vice President and General Manager of Automotive Nvidia Rob Csongor, "It's not useful to compare the performance of Tesla's two-chip FSD computer against Nvidia's single-chip [Xavier] driver assistance system" but the Nvidia DRIVE AGX Pegasus computer outperforms the 144 TOPs of Tesla's chip, running at 320 TOPS and offering AI perception, localization, and path planning. Both companies agree that self-driving cars are the future of the industry and with the embedded, AI-capable, chips, and algorithms they will be able to provide safety, convenience, and efficiency at a better quality level, at the expense of computational power.

## 9.7 Impact on growth and sustainability by compliance for intelligent transport decision systems, Standards

The primary goal of ITS in this domain is to achieve cognitive decisions according to human patterns of situation awareness, perception, and decision making, based on machine perception from different kinds of sensors and data sources and AI-based learning. The processes have to follow human-centered design principles to serve and benefit humans and society as a whole, and to enhance human capabilities by the technology advances achieved toward highly automated and autonomous systems (HumanE AI Vision, Society 5.0 Vision). Compliance checking for decision systems has therefore to follow fundamental principles: technical requirements (safety, security, privacy, reliability, sustainability); human-oriented AI capabilities with a deep understanding of complex sociotechnical systems and ethical considerations.

Decision systems based on AI of the third generation are not recommended in functional safety standards at the time of writing. Particular architectures, which restrict AI-configurations to make an AI-based system safer and more predictable (no continuous machine learning, bias-free training data, guarded/monitored AI components to block unintended behavior, static neural networks validated as "black box" element, adapted safety concepts for AI & ML) are studied and ongoing research. "Big Data" collected by (IoT) devices over time will form an essential part of AI to guide and validate decision-based systems. Explainability and accountability of machine learning methods are prerequisites to building a validation and verification environment for compliance testing of decision systems according to the fundamental principles mentioned earlier.

In the specific AI-Standardization Group ISO/IEC JTC1 SC42, there is ongoing work on AI and decision taking on a general level which should be taken into account and gives important indications what to consider for compliance checking of decision systems against high-level goals. This covers primarily safety, security and privacy issues of applied AI and decision making. Several organizations have set up ethical principles for future decision systems controlling highly automated/autonomous systems in human environments in a collaborative or noncollaborative manner. Particularly the German Ethics Report and the EC Ethics Guidelines set up generic principles to follow and a decision system must conform to the "Key Guidance for Ensuring Ethical Purpose".

ITS seeks to carefully track, support and influence as far as possible the definition and standardization of AI regulations, having clearly in focus avoiding centralizing and dramatically expanding regulation. ITS requires standards (considering safety, cybersecurity, reliability, availability, maintainability) that can be practically applied, providing guidance and enabling type approval. The AI-related regulations so far exist as additions to hardware and software products, and thus rely on the existing legislative frameworks, which lack of a concrete and detailed plan for handling AI in ITS. For example, whereas the food and drug administration provides a concrete framework for drug regulation, the US National Highway Traffic Safety Administration as part of the department of transportation issues general guidance about the operation of autonomous vehicles without defining every detail. Then it remains on national authorities to provide implementation details per case and this is mainly done for not inhibiting growth. Strict safety guidelines and consumers' and drivers' privacy are driving the development of AI solutions in ITS. The need for privacy and transparency at the same time, as it emerges from the need of insurance companies to investigate accidents, coupled with the requirements for AI transparency and accountability form a field where the automotive industry has to move on with ambiguous goals and increased challenges. The whole AI transparency framework includes developing guidelines for safety, individual privacy protection, algorithm transparency, and explainable decision making in order to turn public opinion in favor of autonomous systems and increase the public trust to them.

## 9.8 Conclusions

Recent and future ITS advances are expected to play a tremendous role in the worldwide industry, as they change the way industrial processes are run, as well as industrial products are designed, promoted, sold, and supported. This chapter attempted to link all ITS advances but with a particular focus on automated driving and AI, with the benefits that the industry expects from the advancements of ITS.

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Chapter 10

# ITS business and revenue models

## 10.1 Business model is important

According to Chesbrough (2006), every company has a business model. Fielt (2014) gave some well-known business models—SouthWest Airlines' low-cost carrier model; Rolls Royce's "power-by-the-hour" model. Chesbrough (2010) argues that the same idea or technology taken to market using two different business models will yield two different economic outcomes. Business model is important. Teece (2010) argued that business models are needed because of the features of market economies where there is consumer choice, transaction costs, heterogeneity among consumers and producers, and competition.

## 10.2 Business model definition

Many different disciplines, such as e-business, information systems, management, entrepreneurship, innovation, strategy, and economics have shown interest in business (Fielt, 2014). In recent years, business models have been the focus of substantial attention by both academics and practitioners. There is no dominant or consistent theoretical agreement on a business model conception or definition despite its popular uses (Zott, Amit, & Massa, 2011; Fielt, 2014). Scholars tend to adopt their own definition that fits in their specific context when defining a business model.

There are many definitions given to what is a business model. Some of the authors define a business model as a system for making money. According to these authors; a business model is an economic concept, which produces revenues and costs (Slávik & Bednár, 2014). From this perceptive, the business model is a set of activities, which create profit due to the cooperation of processes and technologies.

Afuah and Tucci (2001) give the definition of a business model as the method by which a firm builds and uses its resources to offer its customers better value than its competitors and makes money doing so. It describes how a firm makes money currently and in the future. The model emphasizes what enables a firm to have a sustainable competitive advantage, to perform better than its rivals in the long-term (p. 3–4).

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According to Mullins & Komisar (2009), a business model is the pattern of economic activity—cash flowing in and out of the business for various purposes. This dictates whether one runs out of cash or not and whether or not one delivers attractive returns to ones' investors. The business model is the economic underpinning of the business. Debelak (2006) defines a business model as the instrument by which a business intends to generate revenue and profits and how a company serves its employees and customers and involves both strategy as well as an implementation. Chesbrough (2006) argues that a business model is a useful framework to link ideas and technologies to economic outcomes. Others such as Wheelen & Hunger (2010) define business model as a method for making money in the concrete business environment consisting of key structural and operational characteristics of company—how a company earns and creates profit.

A business model based only on economic view does not represent a complex view of the company, argued some authors. These authors argued that a business model should also capture the other side of the business that is creating value. These authors believe a business model is a combination of economic and value view (Osterwalder, 2004; Shafer et al., 2005).

Shafer et al. (2005) gave this definition to a business model. A business model is a representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network. Following this perspective, Osterwalder (2004) defines a business model as a conceptual tool that contains a set of elements and their relationships and allows expressing the business logic of a specific firm. According to him, the business model describes the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams. This business model has nine main building blocks.

Another definition given to business model is by Amit & Zott (2001). According to these authors, a business model shows the content, structure, and governance of transactions designed to create value through the exploitation of business opportunities. It describes how the company operates and creates value through exploitation in a system of transactions. Zott & Amit (2010) later expanded and redefined the business model to be a set of activities, wherefore it is an activity system, still with the same back-bone and thoughts from their research paper from 2001. As an activity system, Zott & Amit (2010) provide a framework that separates the approach into two categories, namely considerations of design elements and considerations of a design theme.

Teece (2010) defined a business model as "… *how enterprises create and deliver value to customers, and then converts payments received to profits*" (Teece, 2010) (p. 173). This model highlights the importance of the customers because they affect and define the successfulness of the business model. According to Teece (2010), it is important to build a business model differentiated to create viability, which is harder for competitors to imitate.

Casadesus-Masanell and Ricart (2010) describe a business model as how a company deploys its strategy to be able to compete. They argue that there is a relation between strategy and business models even though they are distinguished. They argued that business model refers to the logic of the firm, the way it operates and how it creates value for its stakeholders. This means a business model is how one deploys the strategy.

DaSilva and Turkman (2014) argued that the term business model seems to be intrinsically connected with technology-based companies. According to DaSilva and Turkman (2014) business models often encompass strategy, economic model, and revenue model. As it can be seen, there is no agreement among scholars on a clear role for the business model in theory or practice.

According to Casadesus-Masanell & Heilbron (2015), a business model details a comprehensive description how a network, community, organization, or actor creates and sustainably captures value from its activities. Baden-Fuller and Mangematin (2013), give a different definition. They refer business model to both cognitive representations detailing actors' understandings of their business and tangible, material aspects detailing actors' configurations of their business models. Reinhold et al. (2017) argued that from a practical perspective, the concept has intuitive appeal for strategic and entrepreneurial reasoning because it comprehensively describes how value is being created and captured following a procedural input-throughput-output logic.

## 10.3 Components of a business model

The components of a business model describe what a business is made of (Fielt, 2014). Teece (2010) argues that because business model still has no fixed theoretical foundation in economics, it is difficult to identify processes and components, which are necessary for business and would define a creation of value in a company comprehensively and fundamentally. The compositional elements are referred to by different authors as building blocks (Osterwalder & Pigneur, 2010); components (Pateli & Giaglis, 2004); (key) questions (Morris et al., 2005); or functions (Chesbrough & Rosenbloom, 2002)

Mullins and Komisar (2009) argued that a successful business model has five pillars that predetermine the economic viability of the business—The revenue model; Gross margin model; Operating model; Working capital model; and Investment model.

The revenue model is the money that comes from a customer who is willing to buy what the company sells. Gross margin model is the difference between revenue from sales and cost for production, that is, money that is left after payment of direct costs. Operating model includes fixed costs that are indirectly paid for production. Working capital model is cash which must be available to ensure fluent operation until the customer pays for the goods. Investment model describes the usage of money that the company wants to invest for the development of the business. According to these authors, the success of the model depends in the harmony of all five models, working together to create value for customers and profit for the company. The advantage of this model is that it is useful for an analysis of business economy and evaluation of financial health, but it is abstracts from other components of the business model. Its limitation is that the model pays little attention to the value, which is offered to the customer. Therefore, this model is not useful for complex analysis.

According to Christensen & Johnson (2009), a business model consists of four interlocking, interdependent elements—value proposition, resources, processes, and profit formula that, taken together, create and deliver value. The model starts by stating the value proposition for a product or service that helps customers do more effectively, conveniently and affordably for a job that they have been trying to do. The value proposition defines the resources the business must put in place to deliver the value proposition. Resources can be people, technology, products, suppliers, distribution channels, equipment, facilities, brands, and cash. They can be hired and fired, bought and sold, built or destroyed. Processes are ways of working together to address recurrent tasks in a consistent way such as budgeting, development, manufacturing, training, planning, etc. Some processes are visible, codified, consciously monitored, and managed. Other processes are habitual ways of working together to get things done that have evolved over time in response to recurrent tasks. The profit formula defines the gross and net margins the organization must achieve, given the structure and magnitude of the fixed and variable costs inherent in its resources.

The business model of Chesbrough and Rosenbloom (2002) is a conceptual frame-work that mediates between technological development and economic-value creation. The model has six components defining the main function and purpose as follows:

1. Articulation of the value proposition.
2. Identification of a market segment, and the revenue generation mechanism for the firm.
3. Definition of the structure of the value chain
4. Estimation of *cost* structure and profit potential
5. Description of the position of the firm within the value network linking suppliers, customers, complementors, and competitors
6. Formulation of a competitive strategy.

David Watson (2005) has developed a model that evaluates a business model. It has six components—competitors, customers, economy, management, products and suppliers. The competitors are defined by barriers of entry to the market, threat of substitute products, competition within the industry and the advantage of being the first in the market. Customers are evaluated according to their characteristics, types of contracts, and payment rates. Economy of company is analyzed through acquisitions, economies of scale, earning on the growth of another company, dividends, and breakpoint. Management is evaluated by

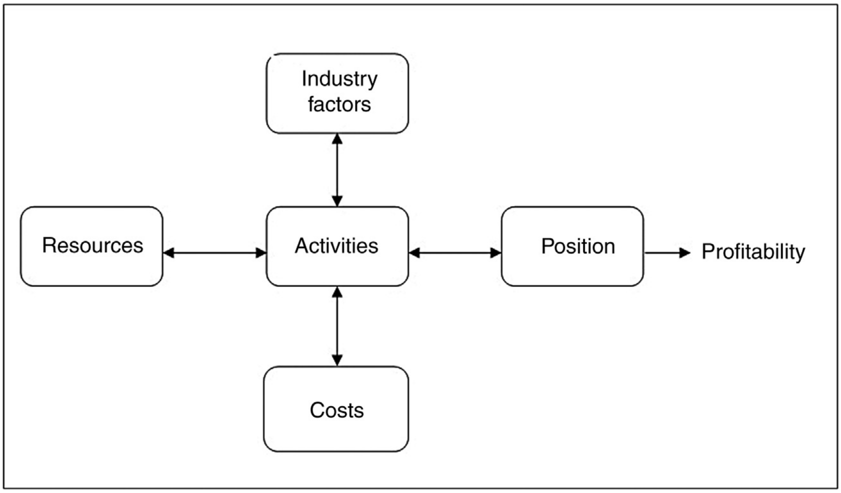


**FIGURE 10.1 Components of business model.** *(Afuah, 2003)*

the moral view, conflicts checking, accounting rules, success in the past and relationship with partners. Products analysis is based on competitive advantage, brand loyalty, creating new products, differentiation, sale places, and innovation of value chain. Suppliers are defined by their negotiation power and opportunistic buying. This uniqueness of the model is that it analyzes sector factors, such as competition.

Alan Afuah (2003) divides the business model into four components (Fig. 10.1) which influence all the activities in a company. The industry factors component analyzes the impact of market elements—competitors, barriers, and customers. Resources help to create value differentiation. Cost brings new type of value—low-cost model. Positions are about looking for the right places, which are not occupied, or the company can deliver to the existing market new and interesting values. Cooperation of these components creates a successful business model and their uniqueness is a source of competitive advantage.

According to Slávik & Bednár (2014), there are several limitations to this model, First, it cannot define the complexity of the company. Slávik & Bednár (2014) argue that a business model should describe a system of creating revenue and value, their relationship with processes, and provide an overview of the business model structure. Second, there is no connection of components into a causal chain that would demonstrate the connectivity and bonds of elements. Third, the model does not allow the clear practical application to concrete numerical results. The model should include components—industrial factors that do not belong to the business model. The external environment may well-determine the characteristics of the business model but is not part of it.

## 10.4 Types of business models

According to Christensen & Johnson (2009), there are three types of business models—solution shops, value-adding process businesses, and facilitated-network businesses. Solution shops are organizations whose resources and processes are structured to diagnose and recommend solutions for complicated problems. Solution shops typically get paid through a fee-for-service revenue model. Value-adding process business models typically bring things in that are incomplete or broken, add value to them, and then ship them out, repaired or completed. These include—automobile manufacturing, restaurants, retailing, petroleum refining, and the work of many educational institutions. Value-adding process businesses usually have a fee-for-outcome revenue model. Facilitated network businesses are organizations where the same people buy and sell and deliver and receive things from each other. The companies that make money in these industries are those that facilitate the effective operation of the network. Typical business models are—bricks-and-mortar; distributor; manufacturer; franchise; eCommerce; nickel-and-dime; retailer; etc.

## 10.5 Business model canvas

The business model canvas (BMC) was developed by Osterwalder (2004) based on his earlier work on business model ontology. In this ontology the elements are grouped into four pillars—customer interface (segments, relationships, and channels), product (value proposition), infrastructure management (activities, resources, and partners), and financial aspects (revenues and costs). The BMC is a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances.

Osterwalder and Pigneur (2010) defined their business model, called canvas, using nine components—customer segments, customer relationships, distribution channels, value proposition, key resources, key activities, partners, cost structure, and revenue streams. This became the most well-known and widely used framework in business models (Osterwalder & Pigneur, 2010). Canvas is used for describing, visualizing, assessing, and changing business models. It uses visual thinking which stimulates a holistic approach and storytelling on design and innovation. Canvas is a powerful visualization tool and clearly shows all the components and their interconnections (Fig. 10.2).

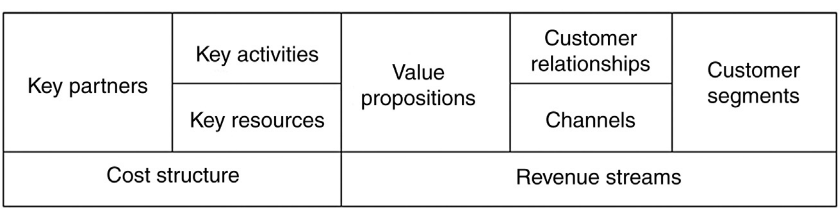


**FIGURE 10.2 The visualization tool.** *(Ref. Osterwalder & Pignuer, 2010)*

The customer segments are defined by five types of market— mass, segmented, niche, diversified, and multisided. Mass market represents a large group of customers with similar needs and problems. Segmented type divides customers into groups based on the same characteristics. There are the products and services tailored to the customer in niche markets. Diversified markets are located in two or more industries with different needs and problems.

According to Osterwalder and Pigneur (2010), creation of a primary value, is the purpose of the business which is defined in the mission of the company. It describes the core product or service that the firm sells to the customer. The extra value (or group of extra values) called value added, which increases a sense of the product or service for a customer, is added to the primary value. The distribution channels are where the company can choose between selling through its own sales network (direct sales: store, salesman, website, application in smartphones, and telephone) or outsource the sale (indirect: intermediator). Personal assistance, which is based on human interaction, is the standard relationship with customers. Cash flow is described by the revenue stream component. Key resources describe tangible resources (production facilities, buildings, vehicles, and equipment) and intellectual resources (brand, knowledge, patents, copyrights, partnerships, customer databases, and human resources–staff and managers). The most important activities involved in value creating are called key activities. Key activities are production, delivery of product, designing, marketing, and selling. The component key partner describes authority or people cooperating with the company. Costs represent a monetary award of production.

According to Slávik & Bednár (2014), the main advantage of BMC is the scheme (Fig. 10.2), which has some universal visualization features that clarify the processes, enable connectivity of al components and can be analyzed with a bird's eye view. Slávik & Bednár (2014) argue that there are several advantages when using BMC. First, BMC as a tool allows organizations to quickly define a business model by filling in nine boxes of information. In doing so, the organization can show how it will create value through the offering for itself—and for its customers or members. For practitioners, it is user-friendly. Second, it can be used in any industry and is flexible. Third, the BMC gives us the structure of a business plan. Fourth, by filling in the boxes, an opportunity is created to have conversations around management and strategy.

However, there are limitations. According to Slávik & Bednár (2014), the limitations are that the BMC is static because it does not capture changes in strategy or the evolution of the model; it does not include purpose of company and competitive environment.

## 10.6 Revenue model

There is often confusion between the term business model and revenue model (Bock & George, 2011), but they are not the same. According to Bock & George

(2011). A revenue model is a framework for generating revenues. The revenue model identifies which revenue source to pursue, what value to offer, how to price the value, and who pays for the value. It is a key component of a company's business model and identifies what product or service will be created in order to generate revenues and the ways in which the product or service will be sold.

A new business will struggle due to costs which they will not be able to sustain without a well-defined revenue model, that is, a clear plan of how to generate revenues. Having a clear revenue model can help a business focus on a target audience, fund development plans for a product or service, establish marketing plans, begin a line of credit and raise capital (Zott & Amit, 2006). According to Zolt and Amit (2006), although it is clearly an important component of a business model, a revenue model does not in itself define a company's business model. A revenue model is defined as the means by which value is captured by a firm.

The main step to develop the revenue model is to determine the types and sources of revenue the business will generate. Sources of revenue from service sales can vary depending on customer type and category, including online, mobile, consumer, corporate, institutional, and/or government. A revenue model includes every aspect of the revenue generation strategy of the business. Revenue can be generated from a myriad of sources, in the form of commission, markup, arbitrage, rent, bids, etc. and can include recurring payments or just a one-time payment.

### 10.6.1 Business model versus revenue model versus revenue stream

"Business model," "revenue model," and "revenue stream," are very often used interchangeably. However, they are different from each other. Alex Genadinik (2014), in his article, "What is the difference between a revenue model, revenue stream and a business model?" summarized the differences.

- A revenue stream is a company's single source of revenue. A company can have zero or many revenue streams, depending on its size.
- A revenue model is the strategy of managing a company's revenue streams and the resources required for each revenue stream.
- A business model is the structure comprised of all aspects of a company, including revenue model and revenue streams, and describes how they all work together.

## 10.7 Types of revenue models

There are many sources that can be used to generate revenue especially with the advent of the internet. According to Pahwa (2019), the following are the top 10 revenue models. Pahwa (2019) gives the definitions as follows

### *Markup*

It is the most common and oldest revenue model in businesses. It involves setting up the selling price of the good by adding profits and overhead charges to its cost price. This revenue model is found among retailers, wholesalers, etc., who act as middlemen and buy the products from manufacturers/other parties before selling it to others.

### *Commission*

A commission revenue model is a transactional revenue model where a party charges commission for every transaction/action it mediates between two parties or any lead it provides to the other party. This model is the most common revenue earning strategies among the online marketplaces where they provide a platform for selling items digitally and charge a commission as a percentage or fixed price on every item sold. Examples of these include affiliates, brokers, and auctioneers.

### *Rent/lease*

Rent/lease revenue model is common where a physical asset is involved. This revenue earning strategy involves recurring (rent) or one-time (lease) payment for a temporary use of the asset.

### *Advertising*

An advertising revenue model is usually adopted by media houses and information providers which usually earn money by including advertisements in the content provided. This revenue model is popular in both offline and online businesses and the company makes money by charging the advertiser: per size of the space offered, thousand impressions or per click on the advertisement.

### *Licensing*

The licensing revenue model is common among inventors, creators, and intellectual property owners which grant a license to use their name, products, or services at a predetermined or recurring cost. It is common among many software companies and legally protected intellectual property (patents, trademarks, copyrights) owners which grant a license limited by time, territory, distribution, volume, etc., to anyone who fulfils their requirements and pays for it.

### *Interest*

An interest-based revenue strategy or an investment based revenue strategy is common among banks and prepaid wallet service providers. Banks usually generate revenue in the form of interest on their offerings (loans) and prepaid-wallet service providers like PayTM & PayPal generate their revenue by depositing the money kept in their e-wallets in escrow bank accounts.

### *Subscription*

A subscription model is an example of recurring revenue strategy. This is a common strategy among entertainment services, and online hosting companies like Netflix, Youtube, Ahrefs, etc., where they provide the specified service for a predetermined periodic cost.

### *Donation*

Many companies provide their products and services free of cost and rely totally on donations paid to them by their customers. Wikipedia is one such company which relies on donations.

### *Arbitrage*

An arbitrage revenue model makes use of the price difference in two different markets of the same good. It involves buying a security, currency, and/or commodity in one market and simultaneously selling the same in another market at a higher price and making profits from the temporary price difference.

### *Fee-for-service*

This model charges the customers for the type of and times the service is provided. This is a pay-as-you-go or pay-per-usage revenue model where the customer pays only for the services he actually used. This revenue model is common in telecom and cloud-based service industries.

The author agrees with Slávik & Bednár (2014) that the business model is a system of resources and activities, which create value that is useful to the customer and the sale of this value makes money for the company. This corresponds to the definitions of Zott and Amit (2006); Zott and Amit, (2010); Zott et al. (2011) that a business model is an interdependent system of activities that explains how an individual or collective actor creates and captures value. The author also concurs with Reinhold et al. (2017) that there are three key features that characterize this definition: first, the focus on an interdependent system of activities, second, the inclusion of individual and collective actors, and finally, the emphasis on creating and capturing value.

## 10.8 Why we need a business model?

Having a business model offers many benefits to a company. First, according to Casadesus-Masanell & Ricart (2011), business model is a vital concept that helps us to understand how and why a broad set of individual or collective actors succeed in sustainably creating, capturing, and disseminating value. Second, Massa et al. (2017) argue that business model focuses on managerial and research attention on several essential interdependencies—interactions among activities and associated choices, links between material and cognitive aspects of business models, and relationships among diverse stakeholders invested in networked value co-production. Theoretically, this concept holds potential because it is grounded in realistic behavioral assumptions (imperfect information, finite cognitive abilities, importance of externalities, and multiple sources of competitive advantage) and combines supply and demand side consideration of cocreating and capturing value. Third, business model is a vital concept that helps in understanding how and why a broad set of individual or collective actors succeed in sustainably creating, capturing, and disseminating value (Casadesus-Masanell & Ricart, 2011).

## 10.9 Value creation

Value creation is created by the customer and it is supported by specific interactions in the customer/provider relationship. According to Normann and Ramirez (1993), the goal of a provider is not to make or do something of value for the customer; it is to mobilize customers to create use-value. This view was further articulated in the sixth foundational premise of Vargo & Lusch (2008) which argues that "the customer is always a co-creator of value." There is no value until an offering is *used*—that is, experience and perception are essential to value determination (Storbacka et al., 2012).

Gronroos (2000) argued that firms exist in order to support customers in their value-creating processes but not to distribute value along a value chain. According to (Korkman, Storbacka, & Harald (2010), firms need to be viewed as extensions of customers' value creating processes but not as extensions of firms' production processes. This paradigm shift allows enhanced opportunities for actors to engage in a wide range of cocreative practices (e.g., Korkman, 2006) that lead to improved co-creation of use-value. Vargo and Lusch (2008) argue that use-value is created as actors-integrate resources in practices. They argue that all economic and social actors are resource integrators, that is, value is created as actors integrate sociocultural resources from market-facing and public-facing entities.

## 10.10 Cocreation

According to Perks, Gruber and Edvardsson (2012)—"Cocreation involves the joint creation of value by the firm and its network of various entities (such as customers, suppliers, and distributors) known as actors. Innovations are thus the outcomes of behaviors and interactions between individuals and organizations" (p. 935).

Co-creation offers many advantages for companies wishing to improve their innovation capabilities from various perspectives. First, cocreation from a customer's perspective, by interaction with a firm allows cocreation of their consumption experiences (O'Cass & Ngo, 2011), enhance customers' brand experiences (Nysveen, Pedersen & Skard, 2012) and strengthen valued relationships

(Payne & Holt, 2001). Second, cocreation can enhance its innovation processes and is the key to unlocking new sources of competitive advantage from an organization's perspective (Prahalad & Ramaswamy, 2004). Third, cocreation highlights the importance of engagement, cocreation and creating compelling experiences in value creation (Lee, Olson & Trimi 2012). Fourth, cocreation offers new opportunities for enterprises (McColl-Kennedy et al., 2009). Fifth, cocreation offers benefits including: better supply chain integration (Jüttner, Christopher and Godsell, 2010); enhanced engagement of employees; improved shareholder commitment (Madden, Fehle & Fournier, 2006); and knowledge sharing with competitors (Kohlbacher, 2007), which occurs especially in "coopetitive" contexts, providing major benefits, but also creating risks (Ilvonen & Vuori, 2013).

## 10.11 Value cocreation business models

The global economy is entering a new era from technology to demography. It is therefore important reassess value proposition, value creation, and value capture that make up the essence of business models. This can open new opportunities for business to thrive. To cope with this changing era, it is important to revise our business models. New business models can provide better blueprints for creating value. The new business model should be based on the co-creation of value. It is the author's belief that the model of Storbacka, Frow, Nenonen and Payne (2012) can be used as a start up for the design of co-creation of value business models. Subsequent sections give a brief overview of the model.

The framework for business model proposed by Storbacka, Frow, Nenonen and Payne (2012)is shown in Fig. 10.3. According to these authors, value creation is no longer perceived to reside within firm boundaries; but rather, value

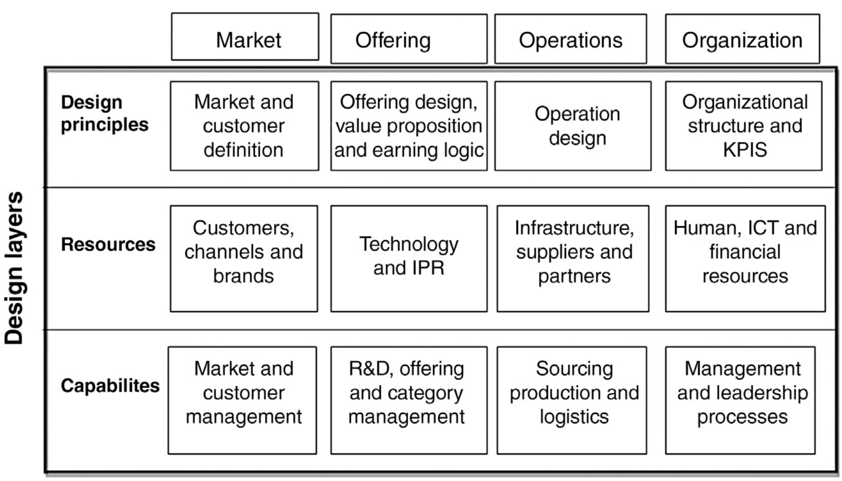


**FIGURE 10.3 A framework for business model.**

is cocreated between actors in a network. These authors define business models as constellations of interrelated design elements, outlining the design principles, resources and capabilities (i.e., design layers) related to markets, offerings, operations and organization (i.e., design dimensions). The key elements of this framework consist of three key design layers—design principles, resources, and capabilities.

The design principles are the first design layers in Fig. 10.3. They describe fundamental ideas or choices that actors must make regarding the business model. Design principles are related to each of the four design dimensions—market, offering, operations, and management.

The market and customer definition principles answer the following questions:

- How does the actor define its market?
- How does the actor position within that market?
- What is the actor's go-to-market or channel strategy?
- Who are the actor's target customers, based on its customer definition?
- How does the actor segment its existing and potential customer base?

The offering design principles outline the offering components available and the possible offering configurations. Value propositions refer to the resource integration promises that actors do to communicate how their offering can increase resource density in a specific context. Earnings logic defines how the actor makes a profit from its operations, it is affected by the pricing logic (selection of price carries and level of price bundling), cost structure and asset structure. The operations design principles define how the actor conducts its operations. The operations design principles depict an actor's "make-or outsource" decisions in all processes and practices ranging from purchasing and production, to customer service and after-sales support. The organizational structure and key performance indicator (KPI) principles help managers to create a cohesive management system and to direct managerial attention to the areas that are most crucial for the viability of the business model.

The second of the design layers in Fig. 10.3 is resources. They are the foundation for cocreation. Customers and brands are the main market resources. Technology and related intellectual property rights are main offering resources. These are crucial in increasing use-value as major improvements in resource density as enabled by advances in technology. Actor's infrastructure, suppliers and partners are main resources associated with operations. The actor's infrastructure also covers items, such as information and communication technology (ICT) infrastructure and the actor's geographical coverage area. The main resources associated with the organization design dimension of the business model are human and financial resources. Availability of resources affects cocreation.

Capabilities are the final design layer in Fig. 10.3. Capabilities are important in business model design because they are manifested in the practices used by the actor in their value-creation processes. They are skills and accumulated knowledge of the organizational processes that enable firms to coordinate activities. The main offering capabilities are offering management and R&D. Operations capabilities outline how the actor conducts its sourcing, production, and delivery processes. Capabilities related to management and leadership enable efficient and effective management of the business model.

The rapid advance of digital technologies such as Internet of Things (IOT), artificial intelligence, data analytics, and cloud computing is blurring boundaries and forcing business to change the way companies operate their business. Companies must continue to evolve their business models to remain competitive. Research in business models should be part of the strategy.

## Questions

What is business model and why do we need it? What are the current business models available for intelligent transport systems? What are the factors we must consider when designing a business model for intelligent transport systems? Develop a business model for an intelligent transport system.

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Chapter 11

# ITS and marketing

## 11.1 Overview

The ability of traditional marketing media (e.g., newspapers, television, and radio) in establishing brand names is continuously degrading among consumers, who lose their credibility on advertisements and become sceptical about any claims that they cannot validate (Ries & Ries, 2002). Marketing experts now invest more time and effort to reach fewer consumers that in the past and must be better prepared and provide more information in order to attract and persuade company decision makers (Gilmore & Pine, 2017). In this evolving landscape, ITS companies are trying novel approaches to attract customers, combining ICT, and social media. Especially social media (e.g., Twitter, Facebook, Blogs, etc.) are constantly used for increasing the visibility of companies, help them establish a brand profile and at the same time influence consumers' opinion on products.

The advent of ITS is innately correlated with ICT and therefore ITS is inherently affected by this new marketing era which requires new methods for making marketing (even more) effective.

In this respect, this chapter presents marketing as viewed on behalf of ITS solution providers, as well as ITS involved stakeholders who are keen on investing on marketing within ITS, so as to better position themselves in a growing exciting market.

## 11.2 Exploiting ITS solutions

ITS solution providers have in general strong interest in investing and exploiting the solutions they develop, not only because they should fit with their strategic individual plans, but also and mainly because they foresee strong potential for exploitation and the creation of a sustainable position in the market. They all share the vision of an ITS asset (i.e., product, solution, service) marketing in a win–win manner. Although ITS involve novel business and revenue models, building upon the Deloitte's program (Weirens, 2014), the components of articulating an exploitation plan inside an ITS context are as follows:

- **Step 1:** It this step it is important to investigate all the relevant market segments and perform additional research to existing research on account marketing and socioeconomics.

The Future of Intelligent Transport Systems. http://dx.doi.org/10.1016/B978-0-12-818281-9.00011-5

- **Step 2:** This step focuses on the analysis of competition (products and services) and their position in the market and community.
- **Step 3:** The third step involves the set up of deployment scenarios and also focuses on the individual and joint exploitation of the various assets. In this step, it defines the market and business models, specifies the collaboration roles, and the cost and revenues from each collaboration. This enables the calculation of the net return over time for each type of market player, being commercial or public.
- **Step 4:** In this step, the business models are validated by the consortium members and the plans for their deployment are fixed.
- **Step 5:** A set of communication activities follows, which aims in raising awareness of the new products/services and solutions and their goals. The proper organization, scheduling, and implementation of such activities are expected to raise their impact especially among stakeholders that can be interested for joint exploitation.
- **Step 6:** The last step comprises the refinement of the business and exploitation plans, as well as the final agreements on the service level, the joint exploitation models and possibly the establishment of new legal entities (joint ventures) when needed.

## 11.3 Marketing ITS solutions in the automotive market

### 11.3.1 Market potential—OEM point of view

For an original manufacturers of equipment (OEM), the customer, distribution networks, and addressed customer segments are clearly settled (considering only the current situation and not taking into account future ownership opportunities and market possibilities). The OEM key contributions for ITS-related solutions are manifold, ranging from test vehicles and test-tracks, to fleets and fleet data, as well as, supplier management and unique distribution networks and impact on domain and standards. The technology developed in the context of ITS will in return be innovative and unique functionalities and customer services, which can be offered the end customer of automated driving vehicles in general, and automated, connected, and electrified vehicles in particular.

### 11.3.2 Market potential—supplier point of view

Following the automotive supply pyramid, Tier1 and Tier 2 come into play, involving more members of the ITS ecosystem. The strength of the OEM in car design and marketing, in collecting parts and assembling the final product is complemented by the specialization of Tier 1 suppliers in making "automotive-grade" systems. Although they serve many car companies, they strongly cooperate with only a few OEMs. The suppliers of Tier 2 have a wider customer range, including customers out of the automotive industry, demonstrate high specialization and a reduced motivation to produce specifically automotive-grade components.

Sometimes this clear separation is a bit blurry, therefore we analyze the strategy to approach this market from a broader point of view.

For automotive suppliers, key partners are, the semiconductor partners, OEMs, and engineering/tool suppliers, which they are addressing directly via dedicated personal assistance (interaction with customer) or creation of community or via deployment of technology solutions at the customer. Their key contributions within ITS solutions are related to the development of new components and E/E architectures, production of systems, and development of key technologies (e.g., automated driving control strategies). The technology developed within ITS will in return be unique value propositions in their specific business, which can be capitalized via revenue streams component and IP sale and engineering service provision.

ITS innovations in general address all components and subsystems of ADAS/automated driving and thus will have an important impact on margins of European industry. Improvements in AI-optimized native hardware, safe, and reliable platforms as well as cognitive intelligence and noncausal reasoning will enable similar reliability, performance, and cost strides also for the computer platforms that support sensor data fusion and decision making in vehicles (Mak, 2017).

### 11.3.3 Market potential—technology/engineering/tool providers point of view

A third essential strategy to approach the ITS market is the technology, engineering, and tool provider point of view. As mentioned, the automotive supply pyramid gives a clear structure for the supplier management. Besides this, technology, engineering, and tool provider support on all of these hierarchy levels. Key partners represent the whole automotive supply pyramid, from OEM to Tier x suppliers and addressing directly via interaction with customer or creation of community is a key factor to success. The key contributions of automotive technology, engineering, and tool providers within ITS solutions are clearly related to specific domain know-how, tool development and support, and the variety of engineering portfolio these companies represent on different levels of the development lifecycle.

In return, the technology developed in the context of ITS will further enhance the unique value propositions in their specific businesses or will be added the current product portfolio under the same business model of licensing the technology.

## 11.4 Marketing strategies for ITS solution providers

### 11.4.1 Overview and phases

This section sets out the communications methodology for ITS solution providers and other ITS-involved stakeholders. It involves outlining key starting points for the strategy and then testing, validating, and refining them through audience research and user feedback received after specific dissemination and pilots. The methodology and the implementation plan to be usually executed in such a context will be carefully outlined within this section.

The communication strategy within an ITS context should utilize corporate communication channels. The overall process followed toward development of the communication strategy will be to:

- consider the target audiences;
- ensure that the message is clearly defined and addresses the needs of each target audience (stakeholder);
- select/fine-tune the dissemination/communication activities to pass on the promotion messages relating to the provided ITS solutions/services/products.

Overall our suggestion is for the strategy to be methodologically organized down into four distinct phases:

1. initial phase,
2. inception phase,
3. implementation phase, and
4. monitoring and improvement phase.

In the beginning of the "marketing period," a primary task will be to identify our audience (stakeholders), their needs and habits. Also, interested parties should focus on (1) refining which are the most effective communication activities that are better tailored to the specific objectives and targeted stakeholders that the solution aims to reach and (2) creating a clear link between the solution's unique selling points and these needs. The proposed coursework is to iterate as follows:

- Briefly describe the audiences in terms of different classes and what we want to achieve with them (i.e., awareness raising, multiplication of results, etc.).
- Identify and use the most suitable tool per audience.

#### *11.4.1.1 Initial phase*

The suggested communication strategy proposes knowing your audience, segmenting your audience into classes and researching your audience to validate the assumption. To segment our audiences and carry out research, we already need to know something about them. For this reason, ITS providers should kickstart a Brainstorming activity to suggest key audience and made a preliminary attempt to size the audiences in classes and discuss the suggested project unique service propositions (USPs). Structuring our audiences will have real impacts on what communication we produce, and how we write, design, and distribute them.

The unique selling project proposition identifies the key points that make a solution unique and worthy of its audience's attention. As such, it underlies much more than the communications strategy and is in effect central to the corporate strategy, therefore involving the identification and implementation of a strategy that positions the product/service as a dynamic, original concept, and clearly communicates its uniqueness.

#### *11.4.1.2 Inception phase*

A deep understanding of our audiences must form a solid foundation of everything we do, and that can only be achieved through audience research—both explicit (e.g., surveys, interviews) and implicit (e.g., online analytics and other metrics).

The steps suggested are:

- **Audience research:** our recommended approach to filling any gaps in our understanding of our audiences;
- **Full personas:** our approach to distilling the research findings into important personas, used to both guide our work and to be customized for national-level strategies;
- **Full audience personas:** including an understanding of their needs, the obstacles they face and their current behavior (e.g., where they currently get information, their social media habits, their preferred method of consuming information);

Structure and characterize these audiences in great detail, allowing us to connect each audience to Transforming USPs, an audience-product-channel matrix should be then prepared to set out a series of products and activities suited to the various audiences, as well as the channels through which the products can reach them; we set out our audiences in a structure and include goals for each of our audiences.

That is all very well—but if we are to achieve our goals, we have to help these audiences meet *their* goals, and we have to make it clear how we can help. The USPs are therefore the flipside of the audience analysis—solution providers must make a compelling, unique case for the question: why should *each* audience pay attention to a solution?

#### *11.4.1.3 Implementation phase*

Suggestions here depend on the nature of the promoted solution, but in general the following types of activities can be used to market ITS-related solutions:

**Events-based communication**—Awareness raising is expected to be impacted positively by active presence in international conferences, workshops, and demonstrations is foreseen by all means and tools—and the organization of at least one microlevel event per time period (e.g., month after the solution/product launch).

**Web-based communication**—Online activities designed as central to the solution website and geared completely toward raising awareness and traffic by encouraging more people to visit the website that is dedicated to the particular solution.

**Print-based communication**—Entails newspapers, journals, etc.

**Press-based communication**—To multiply the impact of the solution toward the different target audiences, we will contact local and international media including newspapers, automotive-related magazines, and journals, as well as initiatives and individual journalists specializing in the domains in order to encourage stakeholders to share our vision and common understanding of what an ITS solution is about.

**Audio–visual communication**—Prepare a campaign video (simple, for the general public to understand) promoting the project and upload it to the projects website, as well as to YouTube/Vimeo and other similar platforms.

**Mailings**. Marketing will be supported by the efficient use of tools such as mailing/distribution lists, which can raise awareness and allow regular contact (e-newsletter).

#### *11.4.1.4 Monitoring and improvement phase*

The aspect of monitoring how effective a strategy is to monitor the impact of all communications where impact indicators and metrics will be monitored and analyzed to improve the cost effectiveness of the communication products and activities via a feedback loop. The different metrics may be monitored in different time cycles. Example metrics include standard website metrics, user behavior metrics, promotional metrics such as backlinks, SEO ranking, etc., quantitative data measured via survey (suggested—under consideration), as well as outreach that covers indicators concerning press coverage, social media, etc.

## 11.5 Conclusions

This chapter has dealt with ITS and marketing. In particular, it has established the fundamentals to exploit an ITS solution; then it has described means to market an ITS solution in the automotive market, whereas in the sequel has presented some specific marketing strategies that ITS solution providers can adopt.

While it is generally accepted that ITS has earned a place in the new marketing era, it is imperative to continuously think and invest in novel marketing practices that are aligned with the latest advances in ITS, so as to be better equipped in trying to position a company/product/service that is related with the newest ITS technologies, in a continuously growing market.

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Chapter 12

# The societal impact of ITS

## 12.1 Introduction

ITS and their latest advances (Artificial intelligence-enabled management systems, autonomous driving, electric-connected vehicles, etc.) are enormously important not only considering the benefits they bring to the economy but also to the society as a whole. The following subsections explain how ITS (with a focus on disruptive technologies) can pave the way for changes in the fundamentals of our society.

## 12.2 Smart mobility

### 12.2.1 Overview

According to the Electric Vehicle Outlook report by Bloomberg New Energy Finance (Bloomberg, 2019) the number of cars produced worldwide is expected to rise, and so does the number and ratio of electric vehicles, which is expected to reach 32% of the world's vehicles by 2040. Europe is the second main car manufacturer after China and it is vital for Europe to keep its strong place in the mobility market. The societal challenges for the smart mobility sector relate to the $CO_2$ emission reduction, improvement of the quality of air especially in urban areas, development of a sustainable mobility plan for all (including the elderly and impaired), reduction of accidents and congestion. The adoption of next-generation ITS is expected to address all of them.

The deployment of ITS will generate an impact on smart mobility and in alignment with the ERTRAC report on automated driving Roadmap (ERTRAC, 2019) in different ways. The social impact of ITS-related technologies concerns the following areas:

- Safety: enhanced traffic safety.
- Increased accessibility: facilitate access to city centers; reducing the time that people spend in traffic.
- Road capacity: better use of available road infrastructure.
- User comfort: increase user's degrees of freedom while activating the automated-driving system.
- Environment: reduce $CO_2$ footprint by multiredundant, electrified propulsion.
- Social inclusion: guarantee access to new ITS for all, including people with disabilities and the elderly.

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The outcomes of ITS deployment will help to realize fail-operational automated vehicles. More precisely, ITS will pave the way to achieve this, by providing the fundamentals of validated concepts for the main missing building blocks—fail-operational sensors, fail-operational sensor fusion, and fail-operational control and E/E architecture relying on human-inspired decision modeling, utilizing AI-based learning control architectures and signal abstraction as basis for cognitive decision making and non-causal reasoning.

Moreover, social impact through ITS will be achieved through carefully considering social and legal requirements for the design of ITS solutions, in order to increase user acceptance and provide a roadmap for the adoption of ITS relevant technologies. In general, ITS will contribute to:

- *Increased safety* primarily through the reduction of human error and therefore the number of accidents (90%–95% of accidents are due to human errors); this has the potential to make road traffic as safe as aviation or rail travel.
- *Increased-road occupancy*, ranging from approximately 50%–300% increase (depending on the penetration rate of connected and automated vehicles and the use of dynamic services such as ridesharing).
- *Reduced perception of travel as lost time*, contributing thus to reduce the “cost” of travel time.
- *Increased mobility* for users that currently cannot drive due to physical, mental, or age-related restrictions
- Increased *accessibility to cities* from peri-urban/rural areas through the provision of automated first/last-mile services and its seamless integration with other public transport systems.

### 12.2.2 Enhancements in traffic safety

The list of human influence factors causing accidents is long. Examples are drowsiness, inattention, distraction, speeding, tailgating, and smartphone use while driving, etc. Many of these can at least be partly overcome by cognitive intelligence and human-like automated driving. The World Health Organization reports about 1.2 million deaths and 50 million injuries in road crashes annually, whereas the number of people killed annually in the United States due to drowsy driving reaches 5000. Fatigue is a major factor for crashes, being behind one out of six fatal crashes on highways since it affects drivers’ attention, reaction time, and ability to control the vehicle on emergency.

In order to confront such risks, in 2014 the European Union has issued a revision on driving licenses, which is mandatory for all member states (EU Directive 2014/85/EU) and complies with the directions of the EU OSA Working Group concerning the drivers with obstructive sleep apnea syndrome (OSAS). OSAS is a chronic disease of the respiratory system that directly correlates with sleepiness, and which could take place frequently, during the day, in a very unpredictable manner. The disease has been included in the accident-risk diseases in the EU directive of 2014 since it has been connected with road-traffic accidents.

According to Commission's estimates, *"25,500 people lost their lives on EU roads in 2016 […]. A further 135,000 people were seriously injured."* Commissioner for Transport Violeta Bulc is worried about road fatalities and invited all stakeholders to work on reducing the number of deadly road accidents in 2020 to the half compared to 2010. In addition, the European Commission estimated that every year economic damage of 174 Billion € is caused by car accidents with human responsibilities.

Thus, making reliable and robust cost-efficient automated vehicles available to a broad range of customers offers strong potential to reduce the repairable economic and nonrepairable human damages. Highly automated vehicles also have the potential to greatly increase road capacity, reducing the time that people spend in traffic and reduce the environmental impact. In addition, productivity can go up, since people traveling in autonomous vehicles can work while being transported.

### 12.2.3 Accessibility and capacity of traffic

The main societal impacts of the automation that ITS introduce are related to enhancing traffic safety *and improved-traffic efficiency*. Research on the safety-related benefits from automated driving is still at its beginning, but the results are already very promising. According to a VTT study for Finland, traffic safety is expected to increase with the advent of automation and the respective impact on traffic flow is expected to be positive at automation level 3 and above. According to the study of the European Transport Safety Council (Townsend, 2016), autonomous vehicles of level 3 will improve the *throughput of the network* and the traffic efficiency allowing vehicles to move faster and safer in waves of controlled speed. Even from autonomy level 2, improved safety will reduce traffic disruptions and congestion, positively affecting the transport system. Virtual patrolling is expected to predict or early detect accidents, and vehicle breakdown events, thus alerting drivers and automated vehicles that can avoid queuing and congestion. This will significantly reduce the ratio of incident-related traffic which is estimated to be one-fourth of the total traffic on road networks.

The technologies brought about by ITS target to increase efficiency in the use of automated driving on all kinds of roads, that is, motorways, rural roads, and also in the urban environment. The efficiency increase is achieved by two factors—(1) ease of access to transportation infrastructure and services built upon and (2) building new applications based on existing application verticals by sharing transportation infrastructure. It can be seen as a further means to support the digitalization of society. With half of the world's population living in large cities, and an expected rise to 70% in the next 30 years, the development of smart cities, where ITS will facilitate urban mobility is expected to boost the economic development of urban centers, which today produce 70% of the world's gross-domestic product.

### 12.2.4 Comfort and enabling of user's freedom

Increasing *the comfort of driving* mainly refers to increasing the degrees of freedom for drivers while reducing car accidents and avoiding injuries and fatalities. At the same time, it is important to reduce time to reach the destination and provide smoother mobility that avoids traffic jams and congestions. Autonomous driving can be a solution to the direction of comfortable and safe transportation without congestions and accidents. Autonomous driving presupposes the existence of holistic ITS solutions, through already developed key insights and technologies to enable the path toward autonomous driving. Autonomous vehicles must be able to detect traffic and weather conditions, identify moving objects such as other vehicles, bikes, and pedestrians and predict their trajectories at any condition (with reduced light, darkness, rain, fog, or snow). Thus, it is necessary to develop solutions that provide reliable and multiredundant perception and propulsion systems that are based on human-like control enabled by cognitive intelligence, knowledge, and noncausal reasoning.

### 12.2.5 Sustainability, energy efficiency, and environment

Another dimension of societal impact concerns the reduction of mobility's environmental footprint. Not only Europe's environmental conscious societies are eagerly looking forward to the integration of clean mobility into their urban lives. The global trend for sustainability is obvious, and automated driving is moving forward driven by significant progress with attractive market-oriented cars. There is a push on many levels (global, EU, national, and organizational) to refine and implement enabling technologies and systems with the effect of fundamental change to our road transport paradigms and embracing the possibilities promised by the transition to automated vehicles. The transition phase from early adopters to the mass market is progressing, with a general and growing awareness that the underlying technology to implement automated driving is gaining a sufficient level of maturity. As mentioned earlier, ITS will harmonize the traffic flow due to foresighted-driving based on knowledge about the other traffic participants and its intelligence to generate the energy optimum speed profile.

According to the analysis of Morgan Stanley, ITSs offer the potential for more than 20% fuel savings, corresponding to 541 billion liters per year and corresponding to about 500 billion US$. 541 billion liters of saved fuel can directly be translated into corresponding savings of $CO_2$ and other emissions. Moreover, ITSs offer significant potential to increase road-network capacity. This potential was estimated by Morgan Stanley to amount up to 80% compared to the current status. Traffic flow harmonization in combination with knowledge about the movement and trajectories of other relevant traffic participants allows driving at higher speeds in shorter distances. This saves space and helps to reduce congestion. Further potential to reduce traffic jam could be generated by intelligent rerouting based on the traffic situation (the current status to guide all vehicles approaching a traffic jam through a narrow bypass is not the best option as this likely leads to an even worse traffic jam in the bypass). In the United States about 11 billion liters of gas are wasted yearly in traffic jams. Assuming just half of it could be saved by cooperative automated driving, enormous benefits would result, such as cost savings, fuel savings, emission reduction, reduction of wasted time, etc.

ITS is contributing to tap the high potential of vehicle automation among others by linking the two big automotive market drivers "automated driving" and "electrification" (for both of them, ITS is a basic enabler) by utilization of fail-operational perception and propulsion systems in order to achieve higher contribution to reaching the emission targets. All of the burning mobility challenges ask for accelerated introduction of electrified, connected, and automated vehicles. Acceleration of the market ramp-up of electrified vehicles is a major topic of ITS. Hybrid vehicles as well as electric vehicles with distributed propulsion, thus vehicles with several energy sources and sinks represent excellent approaches to address the previously mentioned societal challenges. Distributed propulsion systems offer redundancy possibilities. ITS considers the multiredundant propulsion systems as a key and basis for achieving the high safety, reliability, and availability requirements for vehicle automation levels 4 and 5. ITS further enriches the optimization of the multiredundant propulsion systems in view of energy saving using information from the perception system and human-inspired decision modeling.

### 12.2.6 Social inclusion and mobility for all

It is straightforward to think pedestrians and cyclists as vulnerable road users that must be protected from autonomous vehicles as well as "bad" drivers, or driving conditions. However, there are many more user groups, such as impaired or elderly people and young children that use the road network or move in between vehicles, especially in the urban environment. Although the increased safety procedures and vehicle mechanisms (air-bags, passive and active safety systems, etc.) have significantly reduced severe injuries and fatalities among passengers, the number of VRUs that are injured or killed in road accidents is still decreasing slowly. The antidotes, in this case, are (1) to increase drivers' awareness for VRUs and evoke a better and safer driving behavior, and (2) to improve the road infrastructure in order to early alert drivers or autonomous vehicles about neighboring or approaching VRUs.

ITS is an excellent means to support, for example, elderly and disabled people to keep their individual mobility, and to considerably reduce their accident risk while driving a car. With the results brought about by ITS, that is, human-inspired control, automated vehicles will behave like well-trained experienced human drivers, who are driving in a cautious and defensive way, thus considering potential mistakes by other traffic participants and avoiding accidents.

## 12.3 Employment

It is widely known that, unfortunately, manufacturing is being gradually transferred outside Europe, at the risk of outsourcing sooner or later also the R&D and losing the IP rights. The EC has made a clear statement that this negative trend has to be reversed and that investing in production sites and capabilities is necessary to secure our wealth in the future. A proper financial framework is required and already set up by the EU to support this strategy. ITS is a perfect fit for this vision and a perfectly designed action at a European level to increase R&D and to bring manufacturing back to Europe.

### 12.3.1 Educational impact and IP valorization in the EU

The deployment of ITS will generate manifold knowledge on which skills are required by the future digital-industry workforce. ITS will contribute to establishing a matching of skills between concrete industrial needs and academic offerings. The new methods generated in ITS (i.e., cognitive decision making, noncausal reasoning, and human-centered AI for human-inspired decision modeling), based on new scientific development and advanced technology, will increase the opportunities for graduates and Ph.D. holders to work in the mentioned industries. For sure, the concepts developed in ITS can be transferred to other industries and challenges, leading to even higher potentials for highly skilled jobs and benefits from the IP generated through the deployment of ITS.

### 12.3.2 Impact on employment

The deployment of ITS will safeguard existing jobs and build the basis for further growth in employment in the transport and digital industry. This will help to gain technological leadership, competitiveness, and future growth within the concerned business segments.

## 12.4 Conclusions

This chapter has dealt with the benefits of ITS for society. From the analysis above, it can be easily drawn that intelligent transport systems can bring a revolution to several fundamental aspects of our society, such as road safety, inclusive technology and transport-related employment. It lies upon the utilization of ITS to appropriately address all the societal challenges and provide a more comfortable and safer future for all.

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Part IV

# ITS regulations, policies and standards

Chapter 13

# ITS and sustainability

## 13.1 Sustainability

Most organizations today strive to achieve sustainability. Although there are many definitions given to sustainability, there is no agreed definition. The idea of sustainability came from the World's first Earth Summit in Rio in 1992. Brundtland's Report for the World Commission on Environment and Development (Brundtland, 1987) defined Sustainable development as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainability is a process or state that can be maintained at a certain level for as long as is wanted. As a noun, it means the ability to be sustained, supported, upheld, or confirmed. In environmental sciences, the term "sustainable" has been employed for processes that do not harm the environment, do not exhaust all natural resources, and thereby support an ecological balance for a long-term period.

### 13.1.1 Why sustainability is important

The aim of sustainability is to improve the environmental health and quality of life for our society. There are many reasons why sustainability is important for our lives. We need clean air, natural resources, and a nontoxic environment in order to maintain a healthy community. Sustainability must be guaranteed not only for the current generation but also across generations, not only for a country or an organization but also for the wider global community.

### 13.1.2 The pillars of sustainability

Sustainability can be grouped into three categories, or "pillars": environmental, social, and economic. The three pillars must be supported. Sustainability cannot work if one of the pillars is not supported. These three pillars are informally referred to as people, planet, and profits.

#### *13.1.2.1 The environmental pillar*

The environmental pillar is the commonest one. Its aim is to reduce the impact of human activities on the natural systems that support the community and

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environment. These involve reducing carbon footprints, packaging waste, water usage, and their overall effect on the environment. Doing so will have a beneficial impact on the planet and can also have a positive financial impact.

#### *13.1.2.2 The social pillar*

Social sustainability is to develop processes, which maintain a healthy community for its current members but also for future generations. It must have the support and approval of its employees, stakeholders and the community where it operates. This involves treating employees fairly and being a good neighbor and community member, both locally and globally. A business should be aware of how its supply chain operates, whether child labor is used and are workers being paid fairly?

#### *13.1.2.3 The economic pillar*

A sustainable business must make profit. The other two pillars such as environment and social pillars cannot be compromised simply to make profit. However, profit cannot compromise the other two pillars. In order to balance between the three pillars, the economic pillar should include compliance with standards, proper business governance and risk management. A balance between the following goals is usually attempted: keep a healthy and equitable society, protect the environment, and guarantee economic prosperity. The three goals are interrelated and equally contribute to the economic sustainability of the development plan so this balance throughout the plan lifecycle is important.

## 13.2 Sustainable transportation

There is growing interest in sustainable transport. The subject has a huge impact on the sustainability of the planet. It is generally agreed that that current levels of car use, fuel consumption and emissions are unsustainable (Goldman and Gorham, 2006).

Sustainable transportation is a growing concern in urban areas because of increasing urban populations and the recognition of urban contributions to climate change. Cities are now home to a large proportion of the human population and are growing every year. In order to ensure urban survival and productivity, cities need to provide affordable, accessible, environment friendly transportation systems. Additionally, in the face of climate change, urban mobility needs to be addressed more sustainably.

### 13.2.1 Sustainable transport

The European Commission defined sustainable transport as one that meets the needs of the present without jeopardizing the ability of future generations to meet their own needs. It refers to the satisfaction of high mobility levels, with the lowest possible energy and environmental costs aimed at satisfying the demand for mobility by businesses and people (Dirks & Keeling, 2009). Other researchers argue that the term sustainability is "a road transport system in which each user pays at least the full marginal social cost of commuting." The definition of Zeitler (1997) for "sustainable mobility" employs "… any form of human mobility that responds to the various physical (and social) challenges in the least polluting way …" and identifies sustainable mobility in the natural way movement, that is, walking and cycling. According to the definition adopted by the Council of Transport Ministers of the European Union, sustainable mobility can be defined as a "transport system and transport model that provides the means and opportunities to meet economic, environmental and social needs efficiently and fairly," while at the same time "it minimizes avoidable or unintended negative effects and their corresponding costs across the different spatial scales."

According to Richardson (1999, quoted in VTPI, 2004) a sustainable transport system is: "One in which fuel consumption, emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world". The World Business Council for Sustainable Development defines sustainable mobility as: "the ability to meet society's need to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values, today or in the future" (WBCSD, 2004). According to Litman and Burwell (2006), the aim of sustainable transportation is to ensure that environmental, social, and economic considerations are involved into decisions affecting transportation activity. Sustainable transport systems must provide a basic requirement to meet society's and the economy's mobility needs as well as social equity. (Williams 2005).

### 13.2.2 Why sustainable transport is important

Currently, 54% of the world's population lives in an urban area and the United Nations predict that this number will rise to 66% by the year 2050. Traffic congestion is a daily occurrence for commuters in urban areas. This contributes to climate change by producing volumes of greenhouse gas (GHG) emissions (United Nations Habitat, 2015). GHG emissions are identified as a contributor to the changing climate (United Nations Habitat, 2015). According to Rice (2014) and EPA (2014), the climate change will increase overall variability of temperature, precipitation, and wind patterns. This variability will increase the probability of heat waves, flooding and/or drought. Thus traffic congestion problems affect society's quality of life socially, economically, and environmentally. Intelligent transport systems (ITS) have the potential to alleviate the unsustainable impacts of traffic congestion and to improve sustainable transportation systems in the world.

According to Sim, Malone-Lee, & Chin (2001), most important factor for air pollution in the urban environment is road traffic. In 1990, traffic accident deaths ranked ninth among the leading causes of death worldwide, with an estimated 2020 to rise to the third position. Estimates of the economic cost of these losses amount from 2% to 4% of GDP in developed countries. According to several reports, 65% of the European population is systematically exposed to noise levels above 55 dB, high enough to cause nuisance, aggression and sleep disturbance (Abo-Qudais & Abu-Qdais, 2005). In economic terms, congestion is estimated to cost around 2% of GDP in the European Union, with air pollution and noise at least 0.6% of GDP.

In most European countries, the problem of transport is quite acute, with the continuing increase in demand for both passengers and freight, and this is directly linked to the economic development of the European Union. However, this demand is not accompanied by a corresponding increase in the available transport infrastructure and the means of transport available. Thus sustainable transport systems are critical both for quality of life and for the environment at a global and a local level. This means reducing the impact of transport on the economy, society, and the environment.

## 13.3 Intelligent transport systems (ITS)

ITS combine the implementation of technological improvements to a road system with improvements that increase the road system's efficiency. The goals of ITS are to enhance mobility, increase fuel efficiency, accessibility, operating efficiency, safety, and reduce pollution. According to Bekiaris & Nakanishi, 2004Bekiaris and Nakanishi (2004), ITS helps mitigate problems such as traffic congestion, air quality, and safety without constructing additional roads. ITS include: advanced traffic management systems, advanced traveler information systems, advanced public transportation systems, and commercial vehicle operations and others. Traffic congestion has economic, environmental, and safety impacts on society. ITS can provide benefits to reduce traffic congestion and improve road' system efficiency and safety (WHO, 2015).

According to Haque, Chin, & Debnath (2013), three key elements of modern transportation are: Sustainability, safety, and smartness. Because of increasing concerns on environmental issues and climate change, Sustainability of a transportation system has become very important. Besides environmental issues, other intractable problems of a land transport system include traffic fatalities and injuries, congestion, noise pollution, depletion of resources, and inaccessibility to facilities. Traffic accidents and congestion impose a huge economic burden to society. Many strategies and policy directions have been developed over the years to address the problems. According to (Haque et al., 2013), these include: integrating land use and transport planning (Sim et al., 2001), designing compact-city plans (Sung & Choo, 2010), implementing transit-oriented developments (Sung & Oh, 2011), controlling the growth of motorization (Han, 2010), managing travel demand through pricing and financing (Seik, 2000), promoting public transport (Ibrahim, 2003), increasing walking and cycling facilities (Duduta, Shirgaokar, Deakin, & Zhang, 2010), and incorporating environment-friendly technologies (Lopez-Ruiz & Crozet, 2010). These strategies and policies are indeed helpful to create a sustainable transportation system that seeks a proper balance between transportation needs and available resources within and between current and future generations. The author agrees with Haque et al. (2013) that a clear vision of a transport system is needed for identifying and developing appropriate strategies and policies to build an efficient, long-lasting, and safe transport system.

### 13.3.1 Implementing sustainable ITS

Because of its social, technical and economic components, implementing sustainable transport system is a complex process. According to Haque et al. (2013), planning of transport system is usually framed by articulating principles and desirable attributes. May et al. (2001) suggested that there are six overarching objectives of a sustainable transport system. These are (1) economic efficiency, (2) liveable streets and neighborhoods, (3) protection of the environment, (4) equity and social inclusion, (5) health and safety, and (6) contribution to economic growth. Castillo and Pitfield (2010) using these objectives have developed an evaluative and logical approach to identify and rank sustainable transport indicators based on measurability, availability, and interpretability. In their paper, these authors have several indicators showing that managing traffic volume, encouraging cycling trips, promoting public transport, reducing $CO_2$ and other air pollutant emissions, and lowering traffic accidents were the key indicators of sustainability.

According to ECMT (2001), a sustainable transport system is one that:

1. allows for the safe and environmentally harmless basic means of access and development on the individual, business, and societal level, while promoting equity within and between generations;
2. is reasonably priced and runs efficiently, providing choice of transport mode as well as support for a competitive economy and good regional development;
3. keeps production of emissions and waste within the carrying capacity of the natural environment and keeps the consumption of renewable resources and nonrenewable resources respectively within the rates of generation and development of renewable substitutes, while minimizing the impact on the use of land as well as production of noise. This has three major targets: (1) economic development, (2) environment protection, and (1) social equity.

Haque et al. (2013) argue that smart technologies can be used to promote sustainability. Their work in the Singapore experience shows that smart technologies help to implement or escalate various policies and strategies related to sustainability. They mentioned that smart technologies like bus priority signal system, bus lane enforcement system, availability of real-time service information and an integrated multimodal fare payment technology have been helpful to promote public transport as a viable alternative to private transport. Traffic signal coordination system using GLIDE helps to ensure a smooth flow along the corridors and hence reduces congestion, fuel consumption, and emissions. Smart taxi booking system and public transport information sharing system have increased the accessibility for commuters. In addition, the availability of real-time traffic and travel-related information has enhanced motorists' flexibility in route planning for a less congested, faster, and safer trip. The electronic toll payment system is another smart technology, which has been successfully implemented to facilitate the road pricing policy for managing congestion and hence promoting sustainability.

A transport system consists of the means, equipment, and logistics required for the carriage of passengers and goods, including transport networks and infrastructures, nodes, and connections, modes of transport as well as policies for their smooth operation. In addition, the purpose of the transportation system is to coordinate the movement of persons, goods, and vehicles. On the other hand, mobility as a term refers to the ability of people and goods to move easily, quickly, and economically, where it is intended at a speed that reflects free flow or comparatively high-quality conditions (Paris Declaration, 2015). In other words, mobility expresses the ability to arrive at the destination in a time and cost-efficient manner (Hollands, 2008). The definition of a sustainable transport system differs from sustainable mobility in that one does not exclude the other, in many ways overlapping or complementing each other (Bifulco et al., 2014).

Priority must be given to the individual parts of the transport system in order to achieve sustainable mobility. The choice of the quality of transport systems for vehicles (and therefore drivers) or pedestrians should be made. For example, speed or traffic safety, public transport or private vehicles will be given priority (Hernández-Muñoz et al., 2011). In the last 10 years, the European Commission has often referred to urban sustainable mobility as part of the goals and actions to achieve sustainable urban development. Specific guidelines have been proposed for the implementation of sustainable transport systems, such as improving public transport and encouraging mild forms of transport (pedestrian, bicycle). As a result, member states have been adopting urban mobility action plans. The proposed measures in the context of the basic guidelines for urban mobility are:

1. Unified Spatial Planning, Urban Planning, and Transport to address major cities' problems in the field of transport by implementing policies aimed at improving traffic, giving emphasis on public transport infrastructure.
2. Traffic Management with the promotion of public transport, instead of private vehicle traffic (priority to means of mass transport, smart traffic, integrated parking policy, road safety upgrade, etc.).
3. Mild Refurbishments that give pedestrians and cyclists significant usable space.
4. Technologies and Measures for the Environment, such as Vehicle and Fuel Emission Reduction Technologies and Environmental Pricing based on the "polluter pays" principle.

In the context of achieving sustainable mobility, other programs have been developed at regional (e.g., European) level. One of them is the ATTAC project (Attractive Urban Public Transport for Accessible Cities), which aims to improve coordination in the promotion, design, and operation of public transport networks.

### 13.3.2 Sustainable Urban Mobility Plans

The European Commission, in the Urban Mobility Action Plan, has decided to speed up the uptake of Sustainable Urban Mobility Plans (SUMPs). SUMPs are essentially strategic urban mobility action plans, which aim to create a sustainable urban transport system based on existing planning practices, covering the mobility needs of individuals today and in the future. In the White Paper on Transport (EC, 2011), it proposed to examine the feasibility of SUMPs as a mandatory approach for cities of a certain size, as well as the possibility of creating a European support framework for the implementation of SUMPs in European cities (Sustainable Urban Mobility Plans, Planning for People).

The EU countries that are pioneering the adoption of SUMP principles are the United Kingdom (with Local Transport Plans-LTP) and France (with Plande Déplacements Urbains-PDU).

Overall, the objectives of SUMPs are:

**a)** to establish urban transport and sustainable mobility;
**b)** to ensure the accessibility of jobs and services to everyone;
**c)** to improve security and safety;
**d)** to reduce pollution, energy consumption, and gas emissions;
**e)** to increase efficiency and cost-effectiveness for the transport of people and goods;
**f)** to enhance the quality and appeal of the urban environment;
**g)** to improve the health of residents and the quality of the urban environment;
**h)** to improved accessibility and mobility;
**i)** to promote of public transport;
**j)** to develop better spatial planning plans, etc.;
**k)** to provide a better quality of life;
**l)** to use available resources effectively.

## 13.4 Why we need to have sustainable ITS

Transport plays a key role in generating economic progress through trade and mobility, but it also account for global $CO_2$ emissions and air pollution worldwide, particularly due to road freight transport. In this sense, these sectors urgently need to be transformed and made more sustainable. The author concurs with Stephenson, Spector, Hopkins, & McCarthy (2017) that unsustainable consequences include environmental impacts, [e.g. GHG emissions

(Hopkins & Higham, 2016)], social impacts [e.g., social exclusion and isolation (Lucas, 2012)], and economic impacts [e.g., the cost of congestion (Wallis & Lupton, 2013)].

It is imperative that we move to more sustainable transport systems. According to Stephenson et al. (2017), this requires market-based solutions such as shared mobility businesses and the increasing cost-competitiveness of electric vehicles. This is unlikely to occur without carefully designed and integrated government interventions (Geerlings, Shiftan, & Stead, 2012).

## 13.5 Sustainable development goals for ITS

Sustainable development is a complex concept that is subject to numerous interpretations because it involves several disciplines and possible interconnections. It must satisfy the needs of the present without compromising the capacity of future generations, guaranteeing the balance between economic growth, care for the environment, and social well-being.

On January 1, 2016, the 2030 Agenda for Sustainable Development adopted by world leaders in September 2015, officially came into force. The 2030 Agenda is a set of 17 sustainable development goals (SDGs) with 169 targets stimulating actions to move the world onto a sustainable and resilient path. It is an important roadmap guiding policy actions for sustainable development in the next 15 years. The sustainable development must be able to protect the planet and guarantee the global well-being of people. These goals require the active involvement of individuals, businesses, administrations, and countries around the world. They are known as the global goals. These goals are a call from the United Nations to all countries around the world to address the great challenges that humanity faces and to ensure that all people have the same opportunities to live a better life without compromising our planet.

The 2030 Agenda states that sustainable transport systems, along with universal access to affordable, reliable, sustainable and modern energy services, quality and resilient infrastructure, and other policies that increase productive capacities, would build strong economic foundations for all countries (para 27). The text includes five targets that are *directly* related to the transport sector and seven other targets that are *indirectly* related to the transport sector.

Transport contributes *directly* to five targets on road safety (Target 3.6); energy efficiency (Target 7.3); sustainable infrastructure (Target 9.1), urban access (Target 11.2), and fossil fuel subsidies (Target 12.c) emphasize that sustainable transport is not needed solely for its own sake, but rather is essential to facilitate the achievement of a wide variety of SDGs.

Transport also contributes *indirectly* to seven SDG targets on agricultural productivity (Target 2.3), air pollution (Target 3.9), access to safe drinking water (Target 6.1), sustainable cities (Target 11.6), reduction of food loss (Target 12.3), climate change adaptation (Target 13.1), and climate change mitigation (Target 13.2).

Sustainable transportation is the capacity to support the mobility needs of a society in a manner that is the least damageable to the environment and does not impair the mobility needs of future generations (Rodrigue, Comtois, & Slack, 2017). It should contribute to environmental, social, and economic objectives. It is therefore important that we have a policy framework to support sustainable transport, which includes low carbon modes of transport, energy efficiency, and user-friendly transport initiatives, integration of transport and land use planning.

Besides the three major pillars of sustainable development, Rodrigue et al. (2017) argues that we should also consider to the question of whether sustainability should be imposed by regulation or be the outcome of market forces. According to Rodrigue et al. (2017), societies do not contribute to environmental problems at the same level. These authors believe that sustainability can be expressed on two spatial levels:

- global that is long term stability of the earth's environment and availability of resources to support human activities and
- local that is often related to urban areas in terms of jobs, housing, and environmental pollution.

Although the transport sector has the potential to improve the lives of the people, currently there is a lack of a leadership at the global level without a clear set of principles to transform the sector. (Mohieldin & Vandycke 2017), It is important that actions are taken to ensure that we have a plan for sustainable ITS. Possible suggestions are:

- to define clearly the objectives underpinning sustainable mobility;
- to give due consideration for safety, equity, and climate for all road projects;
- to adopt the cocreation of value approach for ITS design;
- to use new technology such as IOT, Big data, cloud computing to support future mobility;
- to plan a strategy for sustainable transport as a priority at local, national and global levels;
- to promote an integrated approach to policymaking at the national, regional and local levels for transport services and systems to promote sustainable development;
- to develop alternative means of transport.

To develop sustainable ITS is not trivial. There are many issues that need to be considered. These issues would depend on the economy, social and priority of the country concerned. No country is an island; the world is interconnected. It is important to remember that there are different stakeholders involved from local, to regional to global levels. Each stakeholder has different values. These different values must be addressed and met. There may be conflicting values between stakeholders. To overcome the different values we must plan the design of a sustainable ITS based on the co- creation of values.

## Questions

1. Why is it important to consider sustainability in intelligent transport systems?
2. How do we design sustainable intelligent transport systems?

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Chapter 14

# ITS standardization bodies and standards

## 14.1 World-level standardization bodies

The main standardization body for intelligent transport systems (ITS) or telematics standards is the International Organization for Standardization (ISO). ISO has released three technical standards on ITS, which concern the management of traffic and travel information. However, there exist many regional associations that define standards at a continent level such as the European Committee for Standardization (CEN), or the European Telecommunication Standards Institute (ETSI) or even national bodies such as the Association of Radio Industries and Businesses (ARIB) in Japan, which further complicate the landscape of standardization in the ITS domain. The standards issued so far cover a wide range of transport systems' aspects ranging from information management and communications to the services delivered to the end-user (Williams, 2008). ISO provides standards for:

- Communications Access for Land Mobiles (CALM), ISO-21210. Also a series of CALM standards such as ISO-21217 on CALM using WLAN, ISO 25111 on CALM using Public Wireless Networks, WIMAX, and other standards, etc.
- Personal data protection in Probe Vehicle Information Services, ISO 24100
- IT security evaluation, ISO 15408 and ISO 15446
- Data interoperability and information exchange, ISO 9160, ISO 9591, ISO 10736, ISO 11577, etc.
- Road Transport and Traffic Telematics, ISO 24534, ISO 24535
- Radio frequency identification for Item Management, ISO 18000
- Geographic and Location-Based Services for ITS, ISO 14825, ISO 17572, ISO 22953

Since ITS operates over a complex ecosystem that comprises humans, vehicles and the backbone network, the standards may relate to the short or long-range wireless communications standards, to the technical specification of ITS, and the technology they employ for information encoding, information privacy, and security, for the geographic/location-based services and for the human-machine interfacing. Under this assumption, ISO 19100 Series of Standards on

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Geographic Information, ISO standards on message transmission and data communication, Identification Technology Standards (e.g., ISO 7812, ISO 18013 for individuals, ISO 3779, ISO 4100, ISO 14815 for vehicles, ISO 24533, and ISO 17358 for cargo items, etc.) and ISO 8072 Open Systems Interconnection (OSI) standard can be considered the basis for the development of more ITS and transport information services.

The mission of the IEEE Standards Association (IEEE-SA) is to develop and promote standards for many industries, including mobile communication which is essential for ITS. The IEEE SA's work on ITS focuses on the specification and standardization of ITS services functionalities and capabilities, and on the definition of interoperability frameworks that can be used for the successful development of ITS solutions. The IEEE Standards for Wireless Access in Vehicular Environments (WAVE) (IEEE 1609 series) define the communication framework for ITS and applications. For example, the IEEE 1609:11-2010 that defines a wireless protocol for exchange of electronic payment data that can be used in ITS, or the IEEE Standard for Security Services for Applications and Management Messages (IEEE 1609.2-2013) and its amendments in 2016 and 2017 that define the secure message formats and their processing in WAVE devices. Similarly, the IEEE 1512 series defines the standards for Common (Traffic) Incident Management Messages for use by centers that handle emergencies. IEEE also defines standards for other means of transport, such as the IEEE Standard for Rail Transit Vehicle Event Recorders (IEEE 1482.1-2013), or the IEEE Standard for Communications Protocol Aboard Passenger Trains (IEEE 1473-2010).

The IEEE ITS (https://www.ieee-itss.org/) society is the driving force behind IEEE attempts in the ITS domain. Its aim is to advance all IT and Electrical Engineering technology aspects in their application to transportation. It comprises several Technical Committees on topics such as:

- Artificial transportation systems and simulation
- Cooperative and connected vehicles
- Human factors in ITS
- Planning and control of transportation and logistic networks
- Naturalistic driving data analytics
- Railroad systems and applications
- Self-driving automobiles
- Smart mobility and transportation 5.0
- Traffic and travel management

and a special Interest Group on Intelligence and Security Information for Transportation Systems.

## 14.2 Continental or national standardization bodies

The CEN is one of the major standardization bodies that issue standards for the European countries. In cooperation with other European organizations for standardization, such as the ETSI for the telecom industry and international technical expert groups (e.g., the Institute of Electrical and Electronics Engineers, IEEE) it adopts and customizes world-level standards to the needs of Europe. For example. the ETSI EN 302 665 document on the *Communications Architecture of ITS* (ETSI, 2010), employs existing ISO standards on *Open Systems Interconnection* (ISO/IEC 7498-1), on CALM Architecture (ISO/IEC 21217) and the IEEE Standard 802-2001 on *Local and Metropolitan Area Networks' Architecture*. It consequently defines a global communication architecture of communications for ITS (ITSC) with a focus on the road transport context. CEN/TC 278 (https://www.itsstandards.eu/tc278) is CEN's branch that works on transportation systems and comprises several Working Groups (WG), that specialize in different areas of ITS, ranging from electronic fee collections to mobility integration and urban ITS (https://www.itsstandards.eu/wgs).

The Transport Protocol Experts Group (TPEG) (https://tech.ebu.ch/tpeg) is a European group of experts that works since 1997 on protocols and applications for supporting advanced traffic information services that allow travelers to roam across different modes of transportation (private and public). The TPEG technology handles the delivery of various types of messages and information (e.g., Road Traffic Messages —RTM and Public Transport Information—PTI) using either binary or XML message encoding. In 2007, it merged with ERTICO-ITS Europe (https://ertico.com) and the mobile. Info project and focused on the development of the Traffic Message Channel (TMC) protocol. ERTICO-ITS Europe partnership comprises more than one hundred public organizations and private companies that represent all major telecommunication and transportation stakeholders, ranging from vehicle manufacturers, traffic, and transport managers to mobile network providers and operators. Today they work on the Alert-C standards and on the implementation of RDS-TMC services together with the Traveller Information Services Association (TISA), which develops and promotes open standards and policies for Traffic and Traveller Information (TTI) services and products (https://tisa.org/). A result of these joined efforts is the Traffic Message Channel (TMC), a transmission technology for messages that convey traffic information. The messages are digitally coded using the ALERT C or the TPEG protocol and broadcasted via conventional FM radio signal as RDS Type 8A messages.

The second generation of the TPEG protocol (TPEG2) provides a data modeling approach for real-time traffic information that can be used by navigation systems. The approach uses UML to define both the binary and XML encoding, which are both parts of the TPEG2 application specification and have been accepted by device manufacturers and messaging service providers as the technology that will replace TMC. TPEG1 and TPEG2 are ISO standards, as ISO/TS 18234 (ISO, T. 18234-1, ISO, 2013) and ISO/TS 21219 (TPEG2-INV) (ISO, T. 21219-1, ISO, 2016), respectively. In addition, parts 9 and 10 of TPEG2 define the structure of service and network information (TPEG2-SNI) and the conditional access information (TPEG2-CAI), respectively. The former defines information delivery from service providers to end-users in a language-independent way, whereas the latter defines the access framework to the content of a TPEG service, which can be subject to the existence of a subscription to the service. The remaining parts of the TPEG2 standard define the UML modeling rules (part 2), the conversion rules to binary (part 3), and XML (part 4), the service framework (part 5), the message management container (part 6), the traffic flow and prediction application (part 18), etc.

The European Car-2-Car Communication Consortium (C2C-CC)(https://www.car-2-car.org/) brings together research institutions and the industry (e.g., car manufacturers and car-part suppliers) under the common objective of developing and deploying cooperative ITS (C-ITS) and services. The Consortium develops, tests, and deploys V2V and V2I short-range communication solutions for improving road safety and road efficiency.

Last, but not least, the Open Geospatial Consortium (OGC) (http://www.opengeospatial.org/) is another international open standards provider that specializes in geospatial standards. The standards are freely available for anyone to use or improve and cover a wide range of domains, which are all implicitly related to ITS, including smart cities, IoT & sensor webs, and mobile technology.

## 14.3 An overview of ITS-related standards

The comprehensive review work of Williams (2008) provides a long list of ITS related standards, mainly focusing on ISO standards, but also on those issued by other bodies. Since ITS cover a wide area of application and require multiple systems to co-operate in a standardized way, the presentation of related standards has to be organized in a way that covers the various system aspects. If we examine ITSs as information systems then it is easier to understand their key components and organize the standards related to each one of them.

*Sensing* technologies are a key component of ITSs. Consequently, proper knowledge of the standards and protocols used at the level of sensors is important for developing such systems. The most important standards for sensing devices are:

- The IEEE 2700-2017 Standard (IEEE, 2017) defines a minimum set of performance parameters for the *basic sensors* in the market and a methodology for measuring the performance in an effort to reduce the overhead for the integration of sensor-based systems and to accelerate time to market. The list of sensors comprises (1) accelerometers, gyroscopes, magnetometers, and combinations for motion monitoring, (2) pressure, temperature, humidity, and light sensors for environmental monitoring, and (3) proximity sensors for collision avoidance applications. The standard specifies the units and distributions for each sensor when it operates in normal and extreme conditions.
- The IEEE 1451 family of standards (Lee, 2000) provides an interface for *smart and networked sensors* and a standardized method, which is known as Transducer Electronic Data Sheet (TEDS), for storing information and metadata for sensors and actuators, such as the sensor id, the calibration

process, the correction data, as well as information related to the transducer's manufacturer. With this model sensor manufacturers are allowed to support multiple protocols and networks, given that the provide the necessary information for them, thus adding to the interoperability of the transducer across different networks and making transducers network independent.
- The OGC's PUCK Protocol Standard (O'Reilly & Reed, 2014) is used by instruments that interconnect through Ethernet or RS232 and defines a standard protocol for storing and retrieving data and metadata from the instruments. It is mainly used for marine applications and has already been implemented in the firmware of many instruments.

*Communication* technologies are another key component, which handles the connectivity between the ITS core and its sensing and actuating components (Ali, 2014). All the data collected by the sensors of an ITS must be communicated to the processing nodes and all the output decisions and actions of this process must be communicated to the actuators and actors (end-users) of the system in order to support an informed decision making. Depending on the application goal, which can be either monitoring, control or safety, and different sensor network standards are more appropriate. Wireless sensor network standards comprise among others:

- The ZigBee standard (https://zigbee.org/) was mainly developed for providing low-cost wireless connectivity in short distance and gives priority on low-power consumption over data rate and response-time delay. It supports various network topologies, with tree topology being the best choice for large-scale applications. It has been employed for monitoring applications in ITS (Heredia et al., 2019).
- The WirelessHART is an alternative of ZigBee (Jindal & Verma, 2015), which extended the Highway Addressable Remote Transducer (HART) protocol in factory automation. WirelessHART supports bi-directional field communication, but avoids unnecessary communication costs and ensures long-battery life. This is achieved by implementing on-demand communication. It uses a flat mesh-network topology, where all field devices that form the network serve simultaneously as a signal source and a repeater. In the physical layer, it employs the IEEE 802.15.4- 2006 standard and defines all other communication layers.
- Other standards which are quite popular for industrial automation systems, such as ISA100.11a and WIA-PA are not very frequently used in ITS.

*Cooperation* of system components (vehicles, infrastructure, etc.) is very important for the development of ITS and thus several standards (Festag, 2014) have been defined in this direction:

- The OGC (Open Geospatial Consortium) defines a series of open standards, known as the Sensor Web Enablement (SWE), which comprises of data models and XML encoding that allow describing sensors, actuators, and processes. The key component of SWE is Sensor Model Language (SensorML). The OGC has worked with IEEE and the Marine Plug-and-Work Consortium to harmonize SWE standards with the IEEE 1451 standard and with the PUCK standard, respectively at the web application level. This provides sensors with the ability to expose web interfaces and thus being easily interconnected in an ITS.

- The Cooperative ITS (C-ITS) is a protocol stack defined for the vehicle to infrastructure communication part of ITS (Uhlemann, 2015; Festag, 2014). In the access layer, it defines ITS-G5 for Europe and Wireless Access in Vehicular Environment (WAVE) for US, both as specializations of the IEEE 802.11-2012 standard. The networking layer employs GeoNetworking whereas the Basic Transport Protocol (BTP) is used in the transport layer. However, internet protocols such as IPv6 coined with TCP, SCTP or UDP are also supported in the transport layer. At the top layers of applications and facilities, protocols as CAM or DENM are used for communicating vehicle state information, traffic or road condition information in the area, and supporting the development of safety and traffic efficiency applications. Applications standards of C-ITS define minimum requirements for road-hazard signaling (RHS) applications, or collision-risk warning (CRW) applications in intersections (ICRW) or everywhere (longitudinal CRW). Finally, security- and privacy-related standards build on ETSI standards for PKI enrollment (ETSI TS 102 940), data integrity (ETSI TS 102 942), authorization (ETSI TS 102 097), and confidentiality (ETSI TS 102 941) and define different trust assurance levels (TAL). The set is complete by standards for decentralized congestion control and test standards for verification of conformance to base standards and to industrial specifications.
- As far as it concerns smart transportation, several countries have issued standards that cover short-range communications, electronic tolls, traffic information services, etc. (Ge et al., 2017). The 3rd Generation Partnership Project (3GPP) is a standards organization which develops protocols for mobile telephony (https://www.3gpp.org). V2X (vehicle to everything) specifications use the LTE (Long-term evolution) as their underlying communication technology. Based on the 4G TD-LTE (Time-division long-term evolution), the LTE V2X (Long-term evolution vehicular to X) standard emerges as a competitor to 802.11p and provided support for both direct communication (V2V, V2I) and wide-area communication over a 5G cellular network (V2N).
- CEN/TC 278 working groups are actively engaged with smart transportation applications and provide links to standards and standardization activities among others for—(1) electronic fee collection, (2) public transport, (3) traffic and traveler information, (4) geographical data, (5) traffic information, (6) user interfacing, (7) eSafety (eCall), (8) cooperative ITS, and (9) mobility integration and urban-ITS.

## 14.4 Conclusions

The vision for the ITS standards is to enable the smooth interoperability of vehicles, pedestrians and other network components (sensors and actuators) and the development of ITS services over an interconnected-transportation network, including vehicles, people, and infrastructure in tandem. To do so, national and international committees, cooperations of industrial and scientific partners, expert groups and other standardization bodies are continuously working on the development of standards and protocols that define how ITS components must communicate with one another. The next step in this evolving process must be the harmonization of the existing standards, which will come through international agreements and Memoranda of Cooperation toward universal standards.

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Chapter 15

# ITS programs and strategies worldwide

## 15.1 International strategies for ITS

The interest of global markets in smart technologies for traffic management in large cities, and the increasing interest for sustainable intelligent transport system (ITS) solutions that combine ICT with transport engineering for delivering faster, safer, and secure transport systems, has led to a projected global market for ITS (for 2024) that surpasses US$ 40 billion. On the other side, the yearly cost from road congestion, due to transportation network inefficiencies, is at the scale of billions of dollars in gross GDP for US cities. Similarly, since Asia-Pacific is becoming increasingly urban, with an expected 64% of the population living in large cities by 2050, the demand for efficient public and individual transport increases. It is indicative that car ownership in China surpasses 154 million, with raised negative environmental, social and economic impacts. A study in India revealed that the operational inefficiencies at toll stations result in a total cost for freight transportation industry of nearly USD 5.4 billion, with almost 90% of the cost being the extra fuel that vehicles spend for stopping or decelerating at the tolls, and only 10% being on waiting time (Vanajakshi, Ramadurai & Anand, 2010).

For this reason, governments and local administration (e.g., large cities) across the globe invest in innovative solutions concerning intelligent transportation networks. In the same line, international organizations, experts groups, and think tanks launch ITS development programs and design strategies that will take ITS to the next level.

The US ITS Strategic Plan for 2015–19 (Barbaresso, et al., 2014) aimed to connect each individual citizen (e.g., drivers, passengers, cyclists, pedestrians, etc.) to the community, taking advantage of advances in the "Internet of Things" movement and defined the priorities and the mission of ITS. This connected and collaborative approach aimed to provide safer and more efficient transportation, location-aware information to individuals and predictive analytics and collective knowledge to the transportation community (which includes public agencies and private organizations). The vision of a "connected society" was based on three technology pillars: Connected vehicles, emerging capabilities, and automation, which are complemented by several horizontal building blocks

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such as the use of enterprise data, the interoperability, and quicker deployment of solutions. The ITS Strategic Plan also provided the framework for the ITS Joint Program Office (JPO) and the collaborating organizations to conduct research and development. The ITS Program goals were organized in themes, that include among others: increased safety, enhanced mobility, reduced environmental impact, information sharing, and innovation.

In a similar manner, the strategic plan of the US Department for Transportation for 2017–21 (US Department of Transportation, 2016) focused on R&D and defined four critical transportation topic areas:

1. public safety by reducing the number of accidents, fatalities, and injuries;
2. improved mobility of people and goods, reducing congestion, and easier access for all;
3. better and durable transportation infrastructure that supports the existing transportation system;
4. sustainable environmental policies that aim in emission reduction.

In the past, EU countries have launched many projects on ITSs and Road Transport Informatics, such as DRIVE for safer road infrastructures or PROMETHEUS for efficient traffic management and have established public-private partnerships that focus on safety such as eSafety, INVENT, and PReVENT (Figueiredo et al., 2001). They also established several agencies that work on ITS projects, such as the Commission of European Communities, and the European Research Coordination Agency (EUREKA), which brings together 19 EU governments and European vehicle manufacturers. In the last decade, EU countries have moved to collaborative approaches for establishing a common infrastructure, achieving interoperability and performing scale economy. EU countries invested in automotive open system architectures, common network protocols (GeoNetworking), communication (ETSI EN 302 665), and messaging standards (cooperative awareness messages and decentralized environmental notification messages) (Sjoberg, Andres, Buburuzan & Brakemeier, 2017). The European Commission promotes green transportation systems in its "European strategy for low emission mobility (https://ec.europa.eu/transport/themes/strategies/news/2016-07-20-decarbonisation_en)".

The secretariat of the Economic and Social Commission for Asia and the Pacific [ESCAP (www.unescap.org)] is the main economic and social development center for the United Nations in Asia and the Pacific. In order to foster the development of ITS in the region and enhance the cooperation among its more than 50 member countries, UN-ESCAP its mandate is to foster and nine associate members. ESCAP provides a policy dialogue platform for discussing issues that cut across ITS and ICT. An ESCAP study on the use of ITS in the region (United Nations ESCAP, 2015), summarizes several effective practices that show how ITS can improve transport users' experience, analyses the areas that need governmental intervention and reasons why a national strategy is essential for the success of ITS projects. The same study provides links to national bodies that define ITS and decide the national strategies, such as the Intelligent Transport Society of Korea (http://www.itskorea.kr), or the ITS of Malaysia (http://www.itsmalaysia.com.my/content.php).

The Chinese government along with the national transportation industry is transforming and introduces new development strategies for ITS, such as "New-Type Urbanization," "One Belt and One Road," and "Smart City", in order to combat the increasing traffic congestion problems in many big cities that affect their competitiveness. The national plan invests in large-scale transportation infrastructure that is expected to gives China a competitive advantage over other developed countries (Huang, Wei, Guo & Cao, 2017). According to the Intelligent Transportation Technology Application Committee of the Transportation Association, the overall market size of the Chinese ITS industry boomed from 25.28 billion to more than 200 billion Yuan, from 2011 to 2020.

The report presented by NITI Aayog and Boston Consulting Group (NITI, 2018) defined major challenges for urban mobility in India, such as the unprecedented vehicle growth (motor vehicles increased from 5.4 million in 1981 to 210 million in 2015), the laxity of enforcement mechanism, the urban pollution and congestion and the inadequacy of public transport. The also set the next goals for the national transportation system, which comprise: (1) safe, adequate, and holistic infrastructure, (2) "peak time" travel optimization, (3) better logistics and goods transport, (4) better and more convenient public transport, (5) shared mobility, (6) nonmotorized transport, and (7) green mobility technologies. The list of actions taken by the Indian government for achieving these goals comprise: (1) the National Electric Mobility Mission Plan (NEMMP) 2020, which was launched in 2013 aiming to sell 6–7 million electric vehicles per year from 2020 onwards, (2) the FAME-India (Faster Adoption and Manufacturing of Hybrid and Electric vehicles) project, (3) the Green Urban Transport Scheme that aims to improve nonmotorized transport, and (4) the National Transit Oriented Development Policy (in 2017) framework that promotes living near metros, monorail, and bus rapid transit corridors.

Japan has developed and revised the public-private ITS initiative/roadmap four times since 2014 and in the latest version (PPITS, 2018) provides a detailed roadmap for the establishment of automated driving systems, studies their social, industrial and economic impact and provides the future directions for data management and sharing as well as for the use of AI. The investment in automatic driving technologies is expected to solve several road traffic issues, such as reducing accidents and congestions but also to create a new mobility service sector and assist Japan's automotive industry to maintain its competitiveness at the global level. The roadmap also defines midterm goals referring to the development of an institutional framework for ITS, the promotion of innovation and safety.

The Australian ITSs industry strategy for 2012–17 (ITS Australia, 2012), aligned with the strategy of most countries, promotes safe driving, smart mobility, and environmental friendly ITS. It also defined the main goals for each pillar, which respectively are: (1) zero accidents based on V2V and V2I communication, (2) zero avoidable congestion by increasing access to information, (3) 50%–70% reduction in transport greenhouse gas emissions using performance monitoring systems for vehicles and promoting electric vehicles. In the strategy document, they provide a map of Australian ITS Industry Participants, which includes governmental authorities, research and development groups, and academia, transport logistics companies, industry associations, and clusters, etc. They also provide the roadmap for this cooperative effort, which comprises the main steps of the Plan-Do-Check-Adjust iterative process and clearly define the roles of the government and the industry. In the last few years, a robust research and development ecosystem has been developed in Australia, which includes the national collaborative research center iMOVE, the Australian Integrated Multimodal Ecosystem, and the national science agency CSIRO's Data61. Australia has announced a reform agenda that builds on ITS, connected and autonomous vehicles, and mobility as a service in order to improve the safety, efficiency, and sustainability of the national transport system (Austrade, 2019).

## 15.2 ITS programs

The United States has long been investing in sustainable intelligent vehicle highway systems and ITSs (Black, 1996). The US DOT's ITS JPO report (Maccubbin et al., 2008) presents various ITS application areas, which are divided into larger sections and target both the infrastructure and the vehicles. The Infrastructure section refers to roadways and refers to safety, preventive maintenance, and monitoring applications for roadways, and freeways. The Management section comprises applications for supporting transportation management centers such as transit and fleet management, traffic, and incident management applications. It also comprises applications that facilitate frequent drivers, such as electronic payment and pricing apps, traveler information services, etc. The freight section contains applications that facilitate freight and commercial vehicle transportation as well as intermodal freight. Finally, the vehicle section describes collision warning and in-vehicle navigation systems.

The activities of the US 2015–19 ITS program of JPO (Barbaresso et al., 2014) are mainly focused on connected vehicles and driven by two primary types of communications technologies: V2V communications that employ the technology of dedicated short-range communications (DSRC) and communications that apart from DSRC can use cellular, WiFi, or satellite networks. In all the remaining blocks, such as automation, interoperability, etc., the focus was on the properly designed development of a national vehicle and transportation system. Many more programs have been provisioned for the 2017–21 period (US Department of Transportation, 2016):

- The US DOT T2 Program focused upon research collaboration, knowledge transfer, information dissemination, and practical application of research.

- The FHWA's Technology and Innovation Deployment Program aims to turn research products into proven technologies and demonstrated practices, and to promote the rapid adoption of technologies and innovations.
- The Pipeline Safety RD&T program supports job creation through the launch of new technology services and protects newly developed technology and intellectual property through US patent applications.

All these programs create an ideal landscape for innovative and applicable ITS solutions to develop and bring together government and private companies that want to invest in the transportation sector.

Berkley's Institute of Transportation Studies has released a series of brief smart investments on ITS and infrastructure (Bayen & Shastry, 2017) that can transform transportation infrastructure and improve the delivery of people and goods. The ideas are based on real-time data exchange and communication, control, and sensing technologies that can allow people and goods to move more quickly, efficiently, and safely. They refer to ITS for roads and connected vehicles, improved road infrastructure that will guarantee high-performance in automation and safety operations, and the use of drones in the low altitude airspace. They also propose the investment in data collection and communication infrastructure that will guarantee the overall system resiliency. They recommend the establishment of public–private partnerships for the quick and efficient implementation of the proposed investments.

The H2020-EU.3.4. Program (https://cordis.europa.eu/programme/rcn/664357/en) addresses the societal challenges that arise from smart and environmentally friendly transport and funds several projects that aim for: (1) resource-efficient transport, (2) faster, safer, and more secure mobility, (3) global expansion of the EU transport industry, and (4) efficient policy making that accounts for the socioeconomic impact of ITS. This program funds the Mobility4EU project (https://www.mobility4eu.eu) (Bierau-Delpont et al., 2019) that developed an action plan for innovative transport and mobility solutions in Europe. The project considers the use of multimodal transport for passengers and goods. The resulting action plan for transport in Europe in 2030 addresses technical topics and other societal issues such as policy, standardization, collaboration, and user acceptance. ETNA2020 (https://www.transport-ncps.net/) is another EU project from the same program that aims to facilitate transnational cooperation for "Smart, Green and Integrated Transport." Several EU projects are researching Hydrogen Mobility, such as the Hydrogen Mobility Europe 2 that addresses the innovations required to activate the hydrogen mobility sector, the FLAGSHIPS project that will demonstrate two commercially operated hydrogen fuel cell vessels in France and Norway, or the joint initiative for hydrogen vehicles across Europe (JIVE and JIVE 2) that will put in operation nearly 300 buses in 22 European cities, thus providing further development of this sector.

The UN-ESCAP study (United Nations ESCAP, 2015) lists some ITS applications in the Asia and Pacific region, such as:

- FASTag, the electronic toll collection system developed in India. FASTag was implemented in 2014 in Delhi–Mumbai and until the end of 2016 has been deployed in more than 350 points along the national highways across the country (Omarhommadi, 2017). Of course, similar systems have been developed in South Korea (the Hi-Pass system) and Singapore (Electronic Road Pricing system), in many EU countries such as Italy (Telepass) and Greece (e-pass), in Canada (Canada 407 Express) and US (E-ZPass).
- The Stochastic Cell Transmission Model jointly developed by Hong Kong and Thailand, which provides traffic information in real-time and allows to develop intelligent traffic management systems.
- The public transport information system of Seoul Metropolitan City, which logs 5 million discrete events every night and combines them with Gb of smartphone data in order to analyze and propose new bus routes and bus stop locations.

South Korea invested almost 3.2 billion dollars on ITS in the period between 2008 and 2020 as part of the national strategy and has established four models for controlling the vehicle emitted signals and its use in traffic management, for collecting vehicle data and managing public transport. Finally, provides a rechargeable smart card like a mobile app (T-money) for contactless payments in public transport vehicles.

Japan began investing in ITS before the millennium, first in Tokyo Area and then nationwide (Tsuzawa & Okamoto, 1989), with computer-based traffic control systems and smart traffic lights, in-vehicle navigation systems, and information systems. This allowed Tokyo authorities to deliver accurate information to citizens and assist them to optimize their travel time. The results of such interventions included a major reduction in commute time and financial gains of almost 6 times the cost of infrastructure. The country also invested in electronic toll collection and rapid emergency and rescue activities, and now builds on setting up a full-scale advanced ICT society that in terms of ITS will cover navigation, assistance, road management, support for pedestrians and many more. Today, Japan has a national standard for e-tolls and invests an approximate of 700 million dollars per year on ITS. The ITS-Spot data system is an interesting vehicle–infrastructure cooperative system, based on a network of 1600 communication devices that connect vehicles with a backbone system that collects and processes data and provides real-time traffic predictions.

In China, the automation of traffic management has been the key to improving transportation efficiency and sustainability and has attracted great attention from the government, which puts a lot of effort and funding to ITS policies and research. China has completed twelve 5-year plans and now implements the thirteenth plan in the row, which aims to develop green and sustainable transportation systems. Before the 2008 Olympic Games in Beijing, the "National

Intelligent Transportation Technology Integration Application Demonstration" program focused on creating a large-scale and integrated traffic management service and introduced key technologies for traffic management and road safety.

## 15.3 Socio and technoeconomic aspects of ITS

ITS are exploited by policymakers at a national level for increasing safety, efficiency, and sustainability in transport. The services are provided at three levels. First, the technology is provided and controlled by the central and local governments (e.g., air traffic control systems, dynamic road signs in autoroutes, traffic management systems, etc.). Then, private companies and local governments develop services in which the central government has limited control (e.g., navigation and car safety systems, advanced car control systems, etc.). Finally, part of the data that are created with this process is shared anonymously as open data, in order to support more services to be developed.

In order to guarantee the longevity and sustainability of ITS solutions is important to study all the social and technological aspects that can be affected. A technoeconomic study on the technical and financial ability of ITS [more specifically of driver assistance systems (DAS), automated highway systems (AHS), and commercial vehicle operations (CVO) for freight traffic] to reduce $CO_2$ emissions (Psaraki, Pagoni & Schafer, 2012) concluded that: (1) the European wide highways can accommodate AHS by devoting one lane for vehicle platooning, (2) CVO systems can have only indirect capacity benefits by reducing the travel time via proper commercial fleet management, (3 the social acceptance for DAS technologies can be negatively influenced from the fear of drivers to lose vehicles' control or the fear of pedestrians and passengers to ride driverless cars, the stress that emerges from the short distances between platooning vehicles and the fear for data privacy breaches.

Further studies introduce more uncertainties and challenges to the sustainability of ITS, such as intelligent transportation cost, the indirect environmental impact, the possible lack of data, and the varying goals and subjective opinions of the multiple stakeholders (Kolosz & Grant-Muller, 2016; Moradi & Vagnoni, 2018). They also defined several tools for exploring the landscape for ITS, including cost-benefit and effectiveness analysis, environmental risk and impact assessment and cost analysis of the whole ITS life cycle. The combined use of such tools is expected to identify the dynamics of smart mobility and ITSs and define how transport managers can early detect the risks of their systems, act, and improve their performance.

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Part V

# The future of ITS applications

Chapter 16

# Transportation network applications

## 16.1 Introduction

Transportation networks comprise any type of vehicle such as (1) cars, buses, and bicycles that move on roads and highways, (2) trains that employ the stable trajectory railway networks, and (3) vessels and planes that move through sea and air following loosely-defined trajectories. Although most research has been performed in road and railway networks (also known as planar networks) that offer a predefined track infrastructure, the other means of transportation have recently gained the researchers' interest. Airline networks and maritime transportation networks have been in the focus of intelligent transportation system developers since they have an always increasing business interest and they have been equipped with sensor and processing infrastructures that increased the amount of data available on a global scale. The Automatic Identification System (AIS) that allows tracking of planes and vessels, the rich information collected in ports and airports concerning passengers (passenger numbers, waiting times, etc. per airport or company), cargo and baggage handling information, and fleet monitoring and management data (e.g., plane delays or landing and take-off times per airport) are few of the data that can be used by the applications that aim in optimizing a transportation network performance.

The main aim of a planar transportation network applications is to smoothly integrate information from the vehicles that operate in the network and conditional data from external sources and develop smarter solutions both for the drivers and the network operators and designers. Among the various solutions that have been developed so far, we distinguish intelligent traffic management, collision avoidance, detection of outlying situations that need an immediate response, and in other prediction and prevention solutions that lead to more efficient transportation networks. Nowadays, railway transportation networks are mostly examined as parts of multimodal transportation networks for cargos and passengers. Recent research also focuses on urban railway transportation systems and proposes solutions that are mostly of interest to the passengers (robustness, flexibility, delay absorption, etc.) (Parbo et al., 2016).

In the case of maritime transportation networks, the two main objectives are the robustness, safety, and efficiency of the network (Peng et al., 2017,

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Tran & Haasis, 2015) and the optimization of vessels' routes. In the first case, the focus is given to the management of congestions in ports (Arguedas et al., 2018) and the overall handling of the maritime network dynamics under varying conditions (Fang et al., 2018). In the second case the combination of real-time information about vessel positions from the AIS system with weather predictions, wave height, and current estimations, led to the design of algorithms that search for the optimum transportation paths for vessels (mainly for cargo vessels), paths that minimize travel time or cost. Weather routing (Christiansen et al., 2013) and voyage optimization (Lu et al., 2015) are two optimization problems with similar solutions but slightly different objectives (safety-based vs. cost-based optimization, respectively). Finally, the "almost real-time" visualization of vessels that sail around the globe is an application that gained the attention of researchers and the industry, that is based on a global network of AIS signal receivers that combine land and satellite stations.

Robustness is one of the main concerns for air transportation networks too. Research in the field studies the structure and dynamics of networks and develops algorithmic solutions that reduce delays, avoid flight cancellations, and optimize the transportation of passengers and goods. The identification of critical nodes (i.e., airports) (Sun et al., 2017), the maximization of edge capacity (i.e., flow between airports) (Yang et al., 2018), and the response to the temporal dynamics of traffic (Sun et al., 2015) are the main issues of optimization algorithms.

All the aforementioned transportation networks have several differences but also share many features in common. However, they share a common core architecture which comprises a set of sensing devices embedded in the moving objects and spread close to the network main routes, a processing backbone that comprises applications, models, and processing infrastructures and a communication network for exchanging useful information between the network and the moving objects.

The three layers of intelligent transportation systems are depicted in Fig. 16.1.

## 16.2 Network management systems

The applications of ITS when it comes to traffic management systems are many and can be broadly divided into two major groups depending on the end-user they are targeting—(1) applications that support drivers in making informed decisions and (2) network operating systems that support operators to monitor and optimize the transportation network performance.

### 16.2.1 Driving-assistance systems

Advanced driver-assistance systems (ADAS), are designed to support humans during driving, with their primary aim being car safety and consequently, the overall safety of the network. Additional objectives can be the optimization of

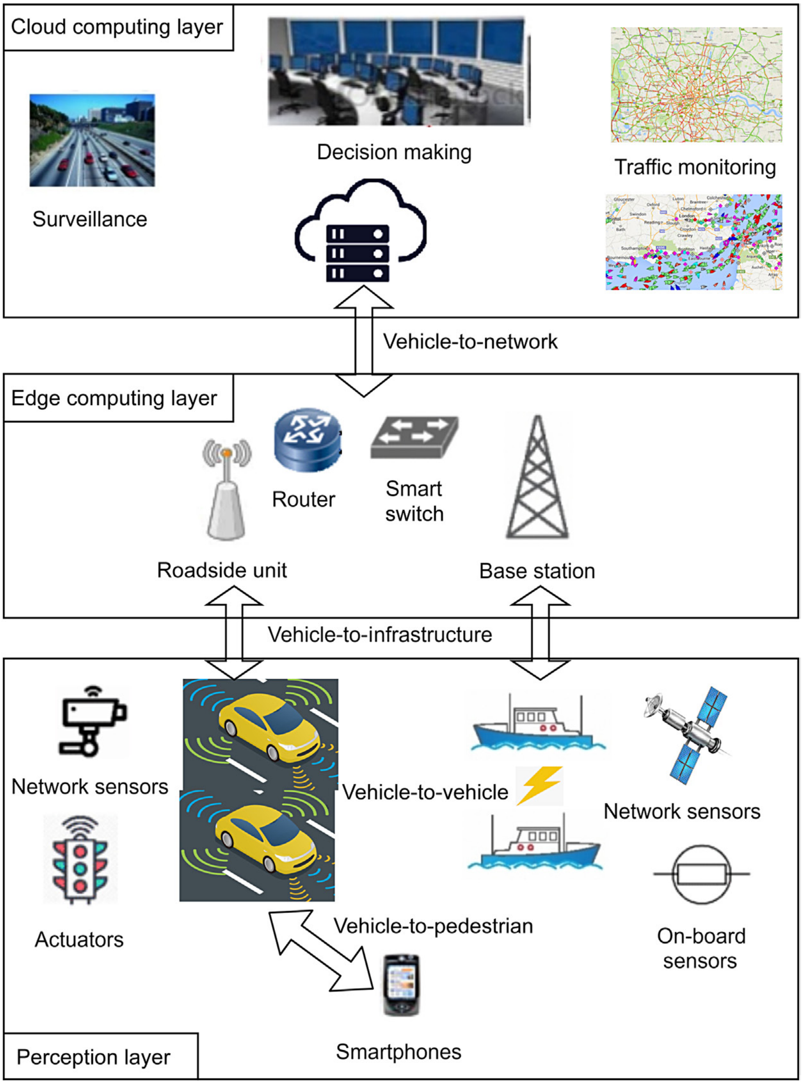


**FIGURE 16.1 The layers of a transportation network system.**

the driver experience while driving, vehicle preventive maintenance, etc. ADAS monitor the condition and position of the vehicle, the condition of the driver and the condition of the network (e.g., the road, the sea, or the air condition) and either notify the driver or take driving decisions, in the case of unmanned vehicles. The main application in terms of safety is collision avoidance, whereas in the case of optimum driving conditions it comprises information about traffic, alerts about congestions, accidents, etc. (Singh et al., 2017), which are reported to the driver. The long list of ADAS services comprises—(1) services that improve safety such as automatic braking for avoiding collisions, blind-spot detection, automatic lane-keeping, and changing, driver monitoring and drowsiness detection, (2) services for preventive vehicle maintenance such as tire pressure and engine monitoring, (3) services that facilitate driving such as adaptive cruise control, automatic parking, hill-descent control, traffic information, intelligent-speed adaptation, and automotive night vision, etc.

### Collision avoidance applications

The contribution of machine intelligence to the collision avoidance problem has a long history and targets all three elements involved in a collision (i.e., the vehicle, the driver and the environment) and all types of vehicles from cars to airplanes. Collision prevention systems use long (radars, LIDARs, AIS, etc.) and short-range sensors for detecting nearby vehicles (blind-spot detection) or obstacles ahead and trajectory prediction algorithms, and notify the driver or nearby drivers to avoid risks.

The use of AIS has been enforced in naval transportations, so all cargo vessels (and many more transportation vessels) are obliged to transmit their position, direction, etc every few minutes using radio frequencies. The respective collision avoidance system of a vessel continuously collects AIS data from its nearby vessels, analyzes their trajectory information, and predicts their near future position. Based on the predicted future positions and the vessel actual trajectory, they are able to early inform the vessel captain and avoid a potential collision. The interest for collision avoidance systems has arisen in the case of road-transportation networks and urban-transportation networks due to the advent of (semi-) self-driving vehicles. The same happened for vessels and unmanned aerial vehicles (Mahjri et al., 2015).

In the case of road-transportation networks, the typical applications that relate to smart-transportation networks for the benefit of drivers were limited to a list that included collision avoidance, collaborative cruise control, automatic detection of driving code violations, emergency alerts (e.g., concerning weather and road conditions, other vehicles, etc). More recently the ability to operate pretrained machine learning models that analyze driver's behavior and vital signals as well as the vehicle's condition allowed to act preventively, to predict potential vehicle malfunctions and early detect driver's distraction and fatigue (Mukhtar et al., 2015).

Tesla (Enhanced) Autopilot (https://www.tesla.com/autopilot), is a driver-assistance system, which uses a camera for lane centering, and changes lanes when the driver agrees, offers self-parking and adaptive cruise control to and from the parking spot.

### Information mediation

Faster network connections between vehicles and the road-side units of the transportation network allowed several applications to emerge that enhance the driver's experience from an information point of view. Information about nearby facilities (gas stations, parking lots, and other POIs), car condition monitoring and just-in-time remote diagnostics (based on On-Board Diagnostics and GSM technology) and notifications (Iqbal et al., 2017), fleet management services, etc., are among the applications that have been developed grace to the ability to collect and communicate data to and from the vehicles.

Back in 2009, the ETSI (European Telecommunications Standards Institute) TR 102 638 standard (ETSI, 2009) categorized the applications focused on V2V, V2I, and I2V communications, which could be of benefit to drivers in three main categories—(1) cooperative road safety, (2) traffic efficiency, and (3) Others that refer to entertainment, fleet management, etc. The complete list of applications is provided in Table 16.1. More recently, NGMN (next generation mobile networks) Alliance identified several use cases of infomediation, augmented navigation, and infotainment (NGMN, 2016), in a more composite automotive ecosystem comprising backend components, communication infrastructure, vehicle, and road infrastructure. Infotainment, vehicle management, traffic management, and security are the main areas of services supported in the backend, vehicle-to-pedestrian and vehicle to network are the two newly added communication dimensions, and decision control and vehicle manipulation are the new functions added on top of recognition. The complete list of functions and examples as given in (NGMN, 2016) is given in Table 16.2.

Similar remote monitoring solutions exist in maritime transportation networks and their main aim is to collect vessel status data (e.g., engine's RPMs, temperature, oil consumption, etc.) and environment information (e.g., waves, wind forces, drift forces, and steering forces) and optimize vessel performance (Tsujimoto & Orihara, 2019) or early detecting and repairing issues in critical engine components (Zoric et al., 2016; Katsikas et al., 2014).

### *Traffic efficiency applications*

The advent of V2V (vehicle-to-vehicle) and V2G (vehicle-to-grid) communication solutions allowed the development of several smart applications that benefited both driver-based and autonomous cars by increasing driving safety and efficiency against traffic (Mueck & Karls, 2018).

For example applications that inform about unexpected car moves (left turn, break, etc.), handle speed harmonization depending on road or weather conditions, etc., are among the ones provisioned for 5G V2V communication. In another example, the ability to share data of LIDAR or video sensor between vehicles allows to foresee bad road or traffic conditions, forthcoming obstacles, and gives the ability to change trajectory and car condition information at high speed and collaborate with nearby vehicles allows applications such as high-density platooning to seem more possible than ever before. Based on the layers depicted in Fig. 16.1, the core architecture that is inherent in all transportation network applications is depicted in Fig. 16.2.

**TABLE 16.1** A list of road transportation applications (according to ETSI).

| Co-operative road safety | Traffic efficiency | Others |
|---|---|---|
| 1. Vehicle status warnings: Emergency electronic brake lights, safety function out of normal condition warning<br>2. Vehicle type warnings: Emergency vehicle warning, slow vehicle warning, motorcycle warning, vulnerable road user warning<br>3. Traffic hazard warnings: Wrong-way driving warning, stationary vehicle warning, traffic condition warning, signal violation warning, roadwork warning, decentralized floating car data<br>4. Dynamic vehicle warnings: Overtaking vehicle warning, lane-change assistance, pre-crash sensing warning, co-operative glare reduction<br>5. Collision risk warning: Across traffic turn collision risk warning, merging traffic turn collision-risk warning, co-operative merging assistance, hazardous location notification, intersection collision warning, co-operative forward collision warning, collision risk warning from RSU | 1. Regulatory/contextual speed limits<br>2. Traffic light optimal speed advisory<br>3. Traffic information and recommended itinerary<br>4. Enhanced route guidance and navigation<br>5. Intersection management<br>6. Co-operative flexible lane change<br>7. Limited access warning, detour notification<br>8. In-vehicle signage<br>9. Electronic toll collect<br>10. Co-operative adaptive cruise control<br>11. Co-operative vehicle-highway automation system (Platoon) | 1. Point of interest notification<br>2. Automatic access control/parking access<br>3. Local electronic commerce<br>4. Car rental/sharing assignment/reporting<br>5. Media downloading<br>6. Map download and update<br>7. Ecological/economical drive<br>8. Instant messaging<br>9. Personal data synchronization<br>10. SOS service<br>11. Stolen vehicle alert<br>12. Remote diagnosis and just in time repair notification<br>13. Vehicle-relation management<br>14. Vehicle data collect for product life cycle management<br>15. Insurance and financial services<br>16. Fleet management<br>17. Vehicle software/ data provisioning and update<br>18. Loading zone management<br>19. Vehicle and RSU data calibration |

### 16.2.2 Network operation applications

When designing transportation networks it is important to identify the key performance indicators (KPIs) that guarantee a successful operation and the long-term objectives related to a continuous improvement of services and an optimization subject to given constraints. The applications may include the study of traffic characteristics of transportation networks that combine multiple means of

**TABLE 16.2** **A list of intelligent automotive functions and applications (according to NGMN).**

| Function | Examples |
|---|---|
| Infotainment | Proximity information, audio/video streaming, navigation |
| Vehicle management | Fleet management, transport/ logistics optimization, border control, tolling, info-mediation/financial services |
| Traffic management | Digital map provisioning/ distribution, traffic/signal control |
| Security | PKI platform, AAA, firewall, DSRC Security credential management system (SCMS) |
| Recognition | V2N: Infotainment, eCall, bCall, diagnostics, software update, digital map update, traffic information, roadside information, PKI update<br>V2I: Reading ahead, cooperative control including merging and lane change could include infrastructure assistance, ETC<br>V2P: Reading ahead, cooperative control<br>V2V: Reading ahead, cooperative adaptive cruise control and platooning,<br>automated cooperative driving<br>On-board sensors: Road, object recognition |
| Decision | Trajectory, control decision |
| Manipulation | Acceleration, braking, steering |
| Roads | Highways, roads, parking, signposts, traffic signals, tollgates |

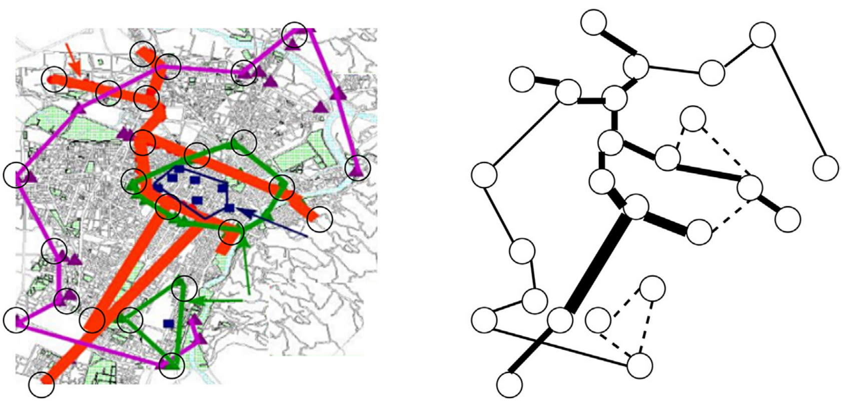

**FIGURE 16.2** **The core architecture of transportation network applications.**

transportation, the assessment of traffic capacity and the assessment of what-if scenarios that examine changes to existing infrastructure and instruments. The analysis of transportation networks and systems may be of medium or long-term nature when it refers to the network design, or of short-term nature when it refers to the daily operation of existing intelligent transportation systems.

The improvement of existing transportation networks and systems includes the concept of optimization, which is related to finding the best measures or solutions that will achieve the objectives set, given some constraints. For example, a measure may be related to the characteristics of the traffic flow and the goal can be the reduction of some of the traffic features including delay times or the environmental impact. Examples of constraints may be the availability of resources, financial, or other, or several technical constraints.

The coverage of a transportation network may span the limits of a single city, country, or continent and the best way for modeling it is using map zones, each one generating and receiving a load of people or products at a certain time period. The origin and destination points are usually modeled as nodes of a network (Fig. 16.3) and the edges connecting two nodes correspond to the

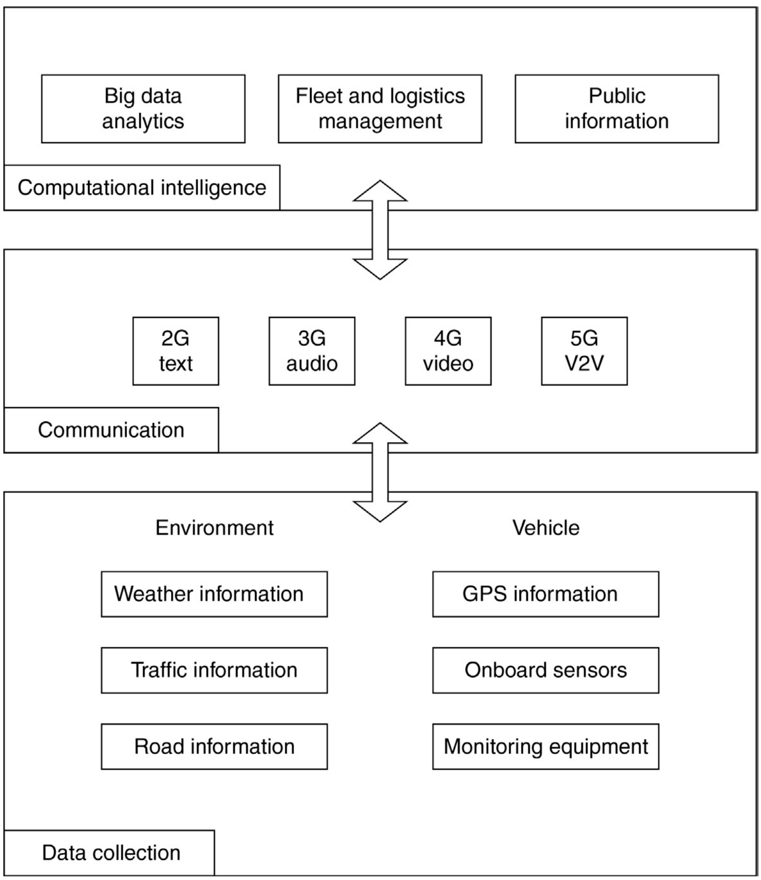


**FIGURE 16.3 An abstraction of a transportation network with information about flows and capacities (thicker lines correspond to bigger flows and different line colors map to different capacities).**

different means of transportation that interconnect the zones. Multiple edges may connect the same two nodes, corresponding to different means of transportation. The flows of people or products generated per period are numbers associated with the origin node and the same holds for the flows that arrive at a destination node. The flows are transferred from the origin to the destination node following paths, comprising the network's edges. The capacity of an edge denotes the maximum flow that can be transported through an edge at a certain time period.

Most of the applications that support network-operation and network-optimization decisions employ the network representation described earlier. For better decisions, they add many more features to the network such as the traversal cost for an edge—if it is fixed- or a function that computes the traversal cost based on the actual load and the edge capacity. The traversal cost is mainly the time needed to cross the edge, but it can also be the distance to cover, or the estimated-fuel cost or the overall cost in money. For example, sea-transportation networks assume different paths for moving from one port to another, which may include naval zones of different traversal cost, depending on the fuel type they allow to be used while moving within them (Życzkowski, 2017; Fagerholt et al., 2015). Similarly, in a road-transportation network, we may consider a different cost when moving between two cities using a toll highway and a toll-free road, when crossing a city during peak or off-peak hours, etc.

When we examine the network operation applications we may divide them into two main subcategories–(1) applications that assist in monitoring the transportation network and optimizing its usage by solving or preventing emerging issues, for example, reducing traffic, responding to a sudden event by rerouting traffic, etc., (2) applications that assist industrial stakeholders in the transportation domain, for example, fleet monitoring and optimization applications, freight transport logistics, etc.

The main concept behind both applications is to combine the network model information with actual usage data from the networking monitoring system, and then use the appropriate algorithms and models to recommend the path/route for each transportation task that will optimize the network usage. In a long-term usage scenario, the applications may recommend changes in the network that will facilitate the above algorithms and will optimize network performance in most conditions.

#### *16.2.2.1 Product transport and logistics*

The use of intelligent transportation systems in the logistics and freight transport industry spans across different (multimodal) transportation networks (rail, automotive, sea, and air) and combines real data with simulations in order to minimize the idle time of the company fleet and products and maximize the flow of goods over the multimodal network (Monios & Bergqvist, 2017). The combination of GPS data and data concerning the vehicle and its load condition allows

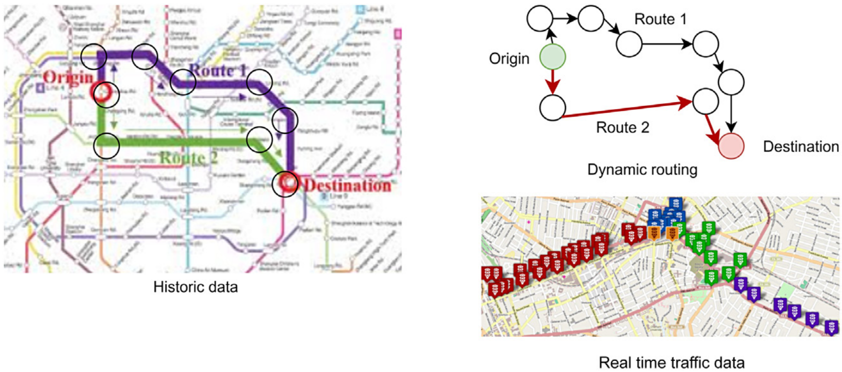


**FIGURE 16.4 A generic transportation network model.**

fleet owners to make informed decisions concerning containers and their contents (Sharma et al., 2016; Mahmood et al., 2019) to prevent delays and search for alternative transportation paths in case of emergency. The same principles apply in any transportation network and rely on the evaluation of flow over a static network, with given loads and capacities, based on historic information, and real-time updates based on information collected by the vehicles that move on the network and from sensors at various network points (e.g., ports, stations, tolls, etc.). The freight transportation is even more interesting within urban environments, where the information is denser and updates more frequently and at the same time the fluctuation in traffic conditions, congestions, and other events that introduce delays in the flow are more frequent (Hesse, 2016). A generic model behind product-transportation networks is depicted in Fig. 16.4. The network model is created based on historic traffic information and is always evaluated using actual network usage data. Using real-time traffic data and a path/route recommendation model it is possible to redirect transports and optimize the network performance.

### *16.2.2.2 Network traffic and safety management*

The ability to dynamically collect traffic data from a transportation network, for example, an urban-road network, an airport network, or a port allows network operators to make informed decisions or respond fast in case of emergency. For example, an accident can be detected in the road network when the average moving speed of vehicles in a section is much slower than usual, traffic congestion can be detected in a network node (e.g., a crossroad) when the incoming flows are much larger than the outgoing ones. In order to respond to such situations, network operators can reschedule the traffic lights of a junction depending on current traffic conditions. They can also combine this action with a traffic rerouting, as it can be pointed by a routing optimization algorithm (Cao et al., 2017).

Similar traffic control and optimization techniques have been proposed for sea and air transportation networks, focusing on the largest ports, and airports around the world that suffer from congestions and flight delays (Balakrishnan, 2016). The proposed techniques have several objectives such as to improve port or airport efficiency (minimize delays and maximize passenger and product flows), improve the network robustness over unpredicted events (e.g., to minimize the propagation of a sudden delay) or guarantee user safety (Stolzer, 2017).

Especially in the case of safety, monitoring, and sensing systems collect data from various points and operations of the network, analyze them and early-detect risks. For example, road monitoring and sensing systems as well as the ability to transfer high definition complex data collected by vehicles to the road network infrastructures allowed to automatically alert drivers for bad or dangerous road conditions, unexpected dangers, and obstacles (animals, fallen objects, bad drivers, etc.) (Madli et al., 2015). Such applications provide increased situational awareness in almost real-time and contribute data that when properly analyzed may reveal network malfunctions and dangers.

#### *16.2.2.3 Smart urban transportation systems*

In the context of cities, intelligent transportation systems are citizen-oriented and citizens are either pedestrians, passengers, drivers, or city-administrative staff. Based on this categorization, smart-urban transportation systems can be divided into the following categories:

1. Parking management systems that provide information on available parking positions and guide the driver to them, allow drivers to pay tolls and fees and gain access to the parking facilities, interface with public transportation means to provide alternative rides,
2. Passenger and driver information systems that include variable message vessels (VMS) for traffic information and for public transport, routing applications on web and mobile phones for passengers, internet services on buses.
3. Municipal-fleet management systems that provide fleet monitoring and management services to the city administrative staff and improve the operation of the urban transportation system. They also allow management of other vehicles and city infrastructure (e.g., management of waste collection fleet and bins), the monitoring of city resources (e.g., municipal fuel consumption, personnel), and allow to respond to emergency incidents and manage crises.

#### *16.2.2.4 More transportation-related applications*

Under the umbrella of network-operation applications, we can also add business-related applications that take advantage of the vehicles' sensing and communication capabilities and deliver smart automation solutions that optimize the operation of the transportation network.

The case of smart-toll systems that automate toll collection with unobtrusive to the driver ways is one such example (Heras et al., 2016). Flexible insurance plans that are based on usage (Tselentis et al., 2017), real-time remote vehicle diagnostics, and preventive maintenance are more applications that protect vehicles from accidents and breakdowns and at the same time assist the smooth operation of the transportation network.

### 16.2.3 The future of transportation network applications

It is evident that the advent of self-driving cars and unmanned vehicles, in general, has disrupted the transportation ecosystem and introduced new solutions and new problems to solve. The triptych of Advanced Driver Assistance Systems (ADAS), Roadside Telematics (RT), and In-Vehicle Information Systems (IVIS) created a new landscape for drivers, network operators, and the whole automotive and transportation industry. On-demand car services are emerging, automated-public transit vehicles, and automated terminals are in the next plans of big cities, remote-controlled vehicles (airplanes, ships, or trucks) seem to be the first step toward unmanned vehicles.

Smart cities of the future, transportation networks of the new decade already design their new applications in this evolving landscape and propose futuristic solutions such as:

- Automated cars that connect airports to nearby car parking stations.
- Smart transit hubs that will serve as centers for autonomous and connected cars, taxis, and urban transportation.
- Shared-use mobility services such as CoGo bike-sharing system, Car2Go, etc.
- Smart corridors that will provide the last-mile connection between transit services and employment centers (Ginther, 2018).
- Mobility on demand for citizens and visitors, with integrated payment options, real-time information, etc., (Austin, 2018).

Apart from the effect on users, infrastructure, and vehicles all these changes affect the governance and regulation of the transportation domain. New ideas have emerged such as the Hyperloop Project (envisioned by Elon Musk and continued by Richard Branson in 2017), which designed a high-speed train moving in reduced-pressure tubes at speeds of up to 700 mph. Other ideas include autonomous helicopters (such as Airbus' Vahana heli-taxi), magnetic levitation trains that already reach 600 and aim at speeds of 1000 km/h, smart roads that will communicate with smart cars and will cover many kilometers. The open question around the present and future of transportation network applications is not about technology and the advances that will support the evolution of the applications, but about the sociotechnical transitions that are necessary for allowing a successful implementation and a wide user acceptance.

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Chapter 17

# Autonomous driving levels and enablers

## 17.1 Autonomous driving levels

The advantages of the use of systems that automatically control the main driving controls of the vehicle such as steering, brakes, and throttle have been early understood by researchers and transportation experts (Hahn, 1996). The ability of the autonomous vehicles to brake on traffic allows them to conserve fuel more efficiently. Effective crash avoidance technologies assist in reducing traffic congestions and cruise control systems reduce greenhouse gas emissions. Finally, interconnected vehicles that exchange information and data [vehicle to vehicle (V2V) communication] and communicate with the highway infrastructure [vehicle to infrastructure (V2I) communication] aim to increase travel safety and reduce travel times and congestions.

When referring to autonomous vehicles, we not necessarily refer to vehicles that are 100% autonomous and can behave equally well in all conditions. There are several studies in the last decade that define the autonomous driving levels.

The early study of Gasser & Westhoff (2012) defined five vehicle automation degrees from driver only to full automation and two more dimensions that define at what level the driver interacts with the vehicle automation, when the automation can be applied (e.g., the speed range and the road conditions that must hold) and for how long. The automation levels are as follows:

- In the "Driver Only" level the responsibility of the manual driving task resides solely to the driver.
- In the "Driver Assistance" level, the driver has permanent control over the vehicle in space and time, but the vehicle automation is active and provides assistive information, notifications, and alerts.
- In the "Partial Automation" level, the vehicle takes over control. However, the driver must monitor the system and be ready to take over control at any time.
- In the "High Automation" level, the vehicle takes over the control again. In this case, the driver does not have to monitor the system at all times but is rather notified by the system when there is a need to take-over.

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- Finally, in the "Full Automation" level, the system takes full control of the vehicle. If a takeover request is rejected by the driver (or fails), the system returns to the minimal risk condition by itself.

They also refer to the degree of automation that can be warning only, control assistance or full automation and the degree of autonomy or cooperation with the driver, which defines a canvas for the various autonomous driving enablers and approaches.

In a similar manner, the US National Highway Traffic Safety Administration defines five levels of automation and ranges from the complete absence of automation (Level 0) to vehicles at the full automation level (Level 4) (NHTSA, 2013).

- Level 0, no automation: It is on the responsibility of the driver to monitor the roadway at all times and operate all the vehicle navigation controls, such as the wheel, the brake, and the throttle. Vehicles at this level may have several driver assistance/convenience systems (e.g., collision warning systems, blind-spot monitors, etc.), but do not have any control authority on the aforementioned vehicle controls. All vehicles that contain only warning technologies but do not take action are classified at this level.
- Level 1, function-specific automation: In this level, the driver still has the overall control, and is responsible for operating the vehicle, but has the option to activate specific control functions, which are automated, but operate independently. Examples of such control functions are adaptive cruise control, crash avoidance (e.g., by dynamic braking), or lane-keeping (e.g., by automatic steering) technologies. They may assist the driver in operating one vehicle control at a time without replacing the driver.
- Level 2, combined function automation: The combined automatic operation of two or more control functions is the main characteristic of this level. The responsibility of roadway monitoring remains at the driver, who has control of the vehicle at all times. However, in a few cases, the vehicle gets the control of the main navigation controls (gas, brake, wheel) and this is done when the driver decides to delegate such authority to the vehicle. For example, when the driver takes his/her hands off the steering wheel and the foot off the pedal at the same time, this can trigger in tandem the operation of the adaptive cruise control and the lane-keeping system.
- Level 3, limited self-driving automation: This level assumes that the vehicle gets full control of all functions that are safety-critical and this is allowed only under specific traffic and environmental conditions. In addition, the driver must be ready to take control back when the conditions change. The transition time must be adequate for the driver (who constantly monitors the roadway) to safely take control of the vehicle, so it is important to early notify the driver. For example, a self-driving car of this level can take full control while on the highway but early notifies the driver when a sign for road construction works appears.

- Level 4, full self-driving automation: All safety-critical functions are handled by the vehicle at all times, as well as the roadway monitoring. This design assumes that the driver is not always available to take control and can apply to occupied and unoccupied vehicles.

The most recent study of the Society of Automotive Engineers (SAE On-Road Automated Vehicle Standards Committee, 2018) provides the J3016™ "Levels of Driving Automation" standard, which defines six different levels of autonomy that cover a wide range of driving autonomy.

- Level 0, no automation: The responsibility for the vehicle's movements is on the driver. Even when warning and alert systems exist, the driver is responsible for how to interpret these elements.
- Level 1, basic driving induction systems: The vehicle offers basic assistance services (e.g., cruise control and parking assistance), but the driver plays a predominant role in driving and driving.
- Level 2, partial autonomy: The vehicles of this level can only be driven under certain conditions and require continuous inspection by the driver. This is the most common level of autonomous vehicles in the market such as Mercedes-Benz and Tesla. At this level, the driver and not the manufacturer is responsible for the vehicle's safety. This makes it easier for companies to take the technology on the road but requires drivers to "remember" that they must be ready to take the lead in order to avoid accidents.
- Level 3, conditional autonomy: Autonomous vehicles of this level are fully aware of the environment and undertake driving, but may require the driver's intervention at any moment. Although the driver does not have to watch the road, he/she must be able to take control when notified. The limits between autonomous driving and human control are a little vague. The driver may need several seconds to intervene and assess the situation, whereas SAE states that "a few seconds" are enough.
- Level 4, high level of automation: The stand-alone vehicle operates all the driving functions, but under certain "scenarios", such as in highway driving, or when the vehicle moves in a well-mapped area. A Level 4 autonomous vehicle may experience problems when it has to move to an unknown area.
- Level 5, full autonomy: At this level, the stand-alone vehicle is capable of handling with ease all circumstances, move under any weather condition as if it was a human. Sensors provide information about everything and specialized software allows the autonomous system to operate fully aware of the environment, without needing prerequisites to function. Level 5 is the most difficult to achieve, but unfortunately, in the transport sector, anything less would be a compromise, since security is just as important as efficiency.

Despite the advances in intervehicle communication and in the communication with the road network, and the advances in artificial intelligence and expert systems that support autonomous driving solutions, there are still several open research issues and decisions to be taken especially in the intermediate autonomy levels, where the autonomous vehicle has to ask the driver to intervene [request to intervene (RTI)], expecting the intervention to occur in a timely manner (Inagaki & Sheridan, 2018). For example, in SAE's Autonomy Level 3, the readiness of the driver when the driving automation issues the RTI must be considered along with the driver's performance to take over control, and the time pressure that the RTI puts on the driver (Happee, Gold, Radlmayr, Hergeth & Bengler 2017). It is also important along with the RTI message to provide information that will assist the driver to control the car on his/her intervention (Petermeijer, Cieler & De Winter 2017).

## 17.2 Technology enablers

In order to achieve the aforementioned autonomy levels, car manufacturing companies equip vehicles with several automations, intelligent decision-making mechanisms and advanced driver-assistance systems (ADAS) that facilitate driving, take control of the car under specific conditions or notify the driver to take control when necessary. Sensors become the eyes and ears of the driver and embedded computing platforms become their brain and nervous system, and the effort remains on making this technology reliable, fault-tolerant, and stable at any condition.Several studies (Banks, Eriksson, O'Donoghue, & Stanton, 2018) and reports (US Department of Transportation, 2017) on Tesla, BMW, and Mercedes-Benz and other autonomous cars provide useful details on the operation of the various in-vehicle systems and how they collaborate for providing autonomy. They also define the areas that require further examination (NHTSA, 2013). At the same time, companies such as Lyft together with carmakers such as General Motors and technology development companies such as Waymo, start new projects and introduce smart technologies that aim to make autonomous driving to the higher levels of autonomy.

The **Automatic Emergency Braking** (AEB) of Tesla Model S, uses a radar/camera fusion module, which has been designed to prevent accidents by early predicting front-to-rear collisions. The module uses an image classification model that has been trained using a large dataset of rear vehicle images and is able to detect the distance from the vehicle in front. The output of the image detection system is fed to the decision making system that includes a forward collision warning system that monitors how the vehicle is moving forward, a dynamic brake support system that supplements insufficient braking from the driver and a crash imminent braking system that automatically activates the breaks if a hazard is detected. Past NHTSA's reports on several AEB systems not only validated the effectiveness of the collision avoidance technologies in many cases but also identified several crash modes that were not validated such as the collisions related to straight movement or left turn that crosses another vehicle's path. Concerning rear-end collision the study focused on the cases where the leading vehicle stops, decelerated or was moving during the accident.

The **Autopilot** ADAS, automates the steering, braking, and throttle comprises a **Traffic-Aware Cruise Control** (TACC) system and an autosteer. The TACC is fed with information from the forward camera and the radar sensor and determines the distance and speed of a leading vehicle in the same lane. If the lane is clean the TACC keeps the driver defined speed, whereas in case of a leading vehicle, the TACC controls the throttle pedal to keep a safe distance from it. The **autosteer** system uses information from the forward camera, the radar and ultrasonic sensors, detects lane markings, other vehicles, and objects and provides automated lane-centering steering control. Both systems are recommended to be used on dry, straight roads, such as highways and freeways and avoided on city streets.With the use of LiDAR and front or rear cameras being a standard in autonomous driving, new *vision and sensing technologies* are gaining space such as the rotating LiDAR sensor, which allows creating 3D surround views and provides obstacle detection and side collision prevention. The next big thing in computer vision for autonomous cars is the research around laser-based (or even camera-based) systems and AI algorithms that fuse sensor data in order to "see around corners". This is done by combining information from reflections and shadows in nearby walls (Saunders, Murray-Bruce & Goyal 2018 O'Toole, Lindell & Wetzstein 2018). Sensor fusion is a key component of Level 5 autonomous vehicles, necessary for getting a better understanding of the vehicle's environment. The most challenging part is data processing and the interpretation of images and signals collected by the vehicle in real time.

One of the main enablers for autonomous vehicles of the middle level is the *user-machine interface*. A smart human-machine interface has to monitor the driver engagement with the driving task, provide information to the driver about the vehicle and road conditions as well as about the system limitations, in order to minimize the risk of mode confusion. At the same time, it must restrict the availability of certain automation when conditions do not apply. For these purposes, the user interface continuously provides feedback from vehicle dynamics and warns the driver when unknown operating conditions are met. In the latter case, the system restricts the availability of the automation in order to prevent confusion. For example, Tesla uses a dialog box to notify the driver to "Always keep hands on the wheel" and to "Be prepared to take over at any time" when the autosteer system is active. Also, information about the distance and speed of the leading car is available on the dashboard. The same car uses an escalating warning series in order to validate the driver's attention to the road and alertness.

Another key technology for self-driving vehicles is the *connected car* technology, which allows vehicles to communicate with others on the road. The term "connected car" encompasses Internet of Things and communication technologies in tandem, and assumes that the car sensor data are transmitted to nearby vehicles (V2V), to the road infrastructure (V2I), to the network (V2N), and to pedestrians (V2P) and the main objective is to enhance safety for vehicles, drivers and pedestrians, making self-driving technology infinitely safer than human-operated cars. Among the services that can be delivered over the connected car technology is the ability to warn for blind spots, for sudden braking of the leading vehicle or forthcoming obstacles, or even to notify for approaching emergency vehicles. Wi-Fi-based short-range communications (e.g., dedicated short-range communication) seemed to be the first option, but existing cellular standards (e.g., 4G or LTE) are currently gaining popularity and become promising with the advent of 5G standard. Data transfer speed, response times, and data security are the main concerns for companies that develop connected car solutions and regulators.

*Artificial Intelligence* is another enabler of self-driving vehicle technology. The abundance of sensor data and the increasing ability of car-embedded systems to perform complex computations moves the interest of researchers from "simple" machine learning algorithms to deep artificial neural network architectures that enable the in-vehicle systems to learn and make its decisions. Learning by the input of a fleet of cars instead of individual instances gives to deep and reinforcement learning models an advantage towards other solutions (KPMG, 2016). The application of deep learning techniques to continuously collected real-life data from different traffic situations allows autonomous cars to become better and better in analyzing and understanding their context and reacting in an informed manner. The future for autonomous systems of that level of expertise seems to be accident free and safe for drivers and pedestrians.

Apart from the *in-vehicle technology enablers*, there are several IT and IoT technology advancements in the *network and infrastructure* that allow autonomous cars to take informed decisions (Johnson, 2017). The road network can be an essential part of the ITS, by hosting a network of on-road devices, which accurately detect road and traffic conditions and early warn approaching vehicles or even activate actuators spread over the road network (e.g., smart traffic lights). Communication with the vehicles is supported by a range of roadside communication devices such as beacons located alongside the road or in the place of traffic signals and communication with the road network operating center can be achieved by connecting the sensors and actuators to the city fiber-optic network. This limits solutions to the urban environment, whereas for highways wireless technology can be employed. The replacement of traffic signals by communication devices that transmit information to the nearby vehicles is a step that further improves autonomous driving, but still has many open issues to be solved. For example, the bad weather conditions that interfere with sensors and introduce noise or interrupt their signal (Ng & Lin, 2016). The redundancy of sensors and sensor types can be a solution to this problem.

### 17.2.1 Beyond technology enablers

Apart from the technology enablers that promote the concept of autonomous driving, there exist more things that have to be considered, as we are moving to higher levels of autonomy. For example, the expectations of the society for increased safety, ethic, and mobility issues such as reduced emissions and traffic, set additional requirements for the new technology. At the same time, they create new opportunities for autonomous vehicles to gain an advantage over traditional manned vehicles.

There are some disruptive changes, which are necessary for the success of autonomous vehicles. For example, the regulations and the legal framework are still underdeveloped in most countries, including Europe and must be altered in order to support the technological advancements. Another change that has to be considered is the physical change of the driver, who no more acts during the whole driving period. This introduces new parameters that must be considered. Finally, the change in responsibility, which emerges from the driver that does not decide in all cases but has to be alert and ready to undertake (CARTRE, 2018).

These disruptive changes bring a series of derived requirements, for a fail-safe operational system, in-vehicle convenience, and improved driving experience, performance, and safety, etc. Since safety is an enabler for autonomous driving, it is important that it also considers the increased freedom of drivers. Safety regulations and passenger safety tests must adapt to the autonomous driving scenario and so must do the interior vehicle design (Büchsner & Reichenbach, 2019).

## 17.3 Research areas

One of the areas that still need further research for improving autonomous driving and establishing higher autonomy levels is that of *Human Factor* and more specifically, the *driver–vehicle interface*. At higher autonomy levels, it is important to guarantee a safe transition between automated and nonautomated vehicle operation and to provide as much information as possible to the driver in order to support the safe operation of the vehicle. Research on the *Human Factor* must evaluate more complex scenarios of interaction and examine different driver reactions in emergencies in order to improve the safety and reliability of the middle levels of autonomous driving. The focus of such scenarios must be on the driver/vehicle interaction, the balance of labor and control authority and the transfer of control between the driver and the vehicle. They should also examine the acceptance of vehicle decisions by the driver and the training requirements for the driver.Another thing that must be defined carefully is the driver's role and its interaction with the automated driving system (Banks & Stanton, 2019). More specifically, the role of the driver in the transition between driving modes, especially when changing between the "driver driving" and the "driver not driving" modes has to be fully defined for every possible scenario, in order to prevent mode confusion. The *transfer of authority* and *responsibility* between the human driver and the system and the disengagements either manual or automatic, along with the conditions they happened and the time required to be accomplished are expected to give useful insights on human trust for the autonomous driving technology and are still to be further studied (Dixit, Chand, & Nair 2016).

Another aspect that must be validated is the *Reliability and Security* of the electronic control systems. Diagnostics, prognostics, and fail-safe mechanisms must be developed for all the safety-critical electronic control systems. Such mechanisms will allow improving the safety of driving and will increase the autonomous driving acceptance. Research on this field must target both safe reliability, which includes functional safety, diagnosis, prognosis, availability, and certification of the system, and cybersecurity by bridging all the system gaps that can be compromised by cyber attacks.

Finally, *System Performance* must be studied in all circumstances. The functional descriptions and the potential restriction for the automation systems of higher autonomy levels and the safety performance requirements must be carefully developed in order to guarantee a minimum level of performance.

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Chapter 18

# Intelligent transport systems and smart mobility

## 18.1 Introduction

According to the United Nations (United Nations ESCAP, 2015), there are several factors that are expected to boost the interest in intelligent transport systems and smart mobility in the urban environment and its surroundings.

- The increase of population that is estimated to reach 9.5 billion by 2050,
- the intense urbanization that results in 85% of the population living in urban regions,
- the population that is growing older,
- the expansion of urban activities to the surrounding regions,
- the increased demand for transportation services both for people and products,
- the increased demand for energy and natural resources, climate change, and natural disasters, are among the reasons that urge the need for new and smarter mobility schemes that adapt to people's needs and demands.

The challenges for the forthcoming mobility schemes can be divided into two main directions— (1) the ability to cover the increasing transportation needs, while providing safe and widely accessible transportation means, and (2) the achievement of several environmental objectives related to the reduction of pollution and reduction of energy consumption and the use of different energy sources. The national strategies for smart mobility comprise among other objectives: (1) integrated and combined transportation networks that take advantage of all the available means of transportation for developing continuous and consecutive transportation paths, (2) multi-modal and flexible transportation that include ride-sharing, bicycle, and mass transportation, (3) a regulatory-framework that reduces accidents and enforces the use of "clean" energy and green mobility. The development of smart and sustainable mobility solutions is part of a holistic framework for smart society development that also comprises—smart economy, smart governance, smart environmental protection, and an upgrade of the quality of life.

The role of public transportation in smart mobility schemes is important since they can support the economy, promote equality, and increase autonomy.

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They are the backbone of the transportation system and serve the largest traffic volume, using the minimum resources, and space. In the new mobility schemes, they are the main transportation hubs, where all other means of transportation (cars, taxis, mini-buses, bicycles, etc.) connect to increase the area of coverage and the efficiency of the transportation system. The design of a smart mobility solution, especially in urban areas must begin and end with public transportation in order to be effective. The *connectivity* among the public means of transportation and the connectivity with other transportation means is the first thing that must be considered in this redesign. The connectivity must be both in space and time, in order to increase land and population coverage and reduce waiting times and the total travel time. Another objective is to increase the *efficiency* of public transportation against private alternatives. This can be supported by the development of transportation hubs and the collaboration of all operators in order to provide single ticket solutions and reduce the time for switching between the different public transportation networks. It is also important to renew public transportation fleet with smart vehicles that provide automation and high quality services (information to the passengers, internet connectivity, etc.), to introduce new mobility schemes that prioritize public means of transportation in specific urban zones and promote the use of smart cards and e-payment applications and replace traditional tickets in order to allow combined public transportation usage schemes.According to the comprehensive review of Mangiaracina, Perego, Salvadori & Tumino 2017, the efficiency of mass and public mobility services is based upon the economy of scale, which is achieved by transporting a large number of passengers and goods and on the better management of physical flows using fewer resources. ITS can improve performance in this direction by automating or supporting decision making, based on richer information that can be collected from various sources. They can support vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connectivity and facilitate data and information exchange. They can also take advantage of the rich data and take better and instant decisions. Finally, they can engage people in this communication network, either as drivers that take decisions for moving safer or faster to their destination or as pedestrians or passengers that share information and use publicly available information to move around the city.

Smart mobility is defined in an urban context and aims in providing better (faster, cheaper, safer, etc.) flows within the city context. Among the cities that have invested in smart mobility one can see large cities mainly from Asia, Europe, and North Americas:

- Singapore uses thousands of sensors to collect data from every aspect of urban life, such as vehicles and pedestrians in its E3A platform: Everyone, Everything, Everywhere, All the Time.
- Dubai has invested in the Smart Dubai project, which involves the use of blockchain for digitizing government, the development of a dashboard (Smart Dubai index) for monitoring city performance at all times and the

fast connection with nearby cities. It is also working on the concept of autonomous airborne taxis and police cars.

- London invested in a smarter underground (Tube) metro system and on the use of bikes for commuting. Network-enabled sensors optimize maintenance costs and offer free wifi to track passengers' movements and plan transport more efficiently.
- San Francisco developed a smart system for detecting and controlling metered parking occupancy and encouraging parking in less occupied spaces. This resulted in reduced-gas emissions and 30% fewer vehicle miles traveled. The city also promotes ride-sharing and is positive on the use of autonomous vehicles by taxi companies.

Boston, Chicago, Seoul, Tokyo, Hangzhou, and Barcelona are among the large cities that have invested in ITS and smart mobility, whereas smaller cities such as Columbus Ohio, Copenhagen, Helsinki follow or even lead, by testing and adopting innovative solutions. Traffic control systems and smart traffic lights, smart parking systems, intelligent infrastructure maintenance systems that reduce downtime, support for autonomous passenger information systems, etc., are a few of the interventions that aim to improve the efficiency of urban transportation. Frost and Sullivan have launched the interactive Smart Mobility City Tracker (https://go.frost.com/LA_PR_AT_FValente_SmartCity_APR19), which evaluates the performance of more than 100 cities in more than 150 data indices that evaluate new mobility solutions, autonomous readiness, digitization, sustainability, etc.

## 18.2 Sustainable smart mobility

Smart cities and intelligent transport systems are two closely related concepts that rely on the use of IoT for connecting physical items (e.g., vehicles, road infrastructure, etc.) in several application scenarios (European Commission, 2016). The city of Santander, Spain, is a city that invested a lot in smart mobility and has attracted the interest of many EU research programs that tested smart urban mobility solutions that combine IoT and ICT technology, city, and public transportation redesign, gamification, and other incentives in order to achieve smart and green mobility. More parking places and mobile apps that help citizens to locate free places, notifications about traffic and other city events, flow estimation models, real-time traffic information and route planning in real-time were some of the services that have been tested over the SmartSantander Platform (http://www.smartsantander.eu).

Despite all the previous government efforts and research projects that tested smart mobility solutions and promoted integrated transportation systems, the Global Mobility report that evaluates transportation (GMR, 2017) shows that—(1) people are still depended on their cars, (2) city centers still have big problems from traffic, (3) the increased traffic brings pollution, noise, and degradation of the urban environment. As far as it concerns the transportation alternatives, public transportation cannot compete for private means especially in areas with disperse population and the network and frequency of public transportation are not satisfactory. Finally, all the green ways of transportation (walking and bicycle) are not so popular and have a limited impact on traffic. The compact and densely-populated cities of East Asia, appear to be more promising for developing sustainable smart-mobility schemes based on mass transportation, whereas in the large but widely dispersed cities of the United States and Australia people still prefer private means of transportation and require a different approach. Large European cities stand in the middle since they have a smaller population size, density, and area. They are usually built around a single city center that promotes green mobility and is connected to the surrounding areas with metropolitan transportation networks.

Smart and sustainable mobility can help in solving many large cities issues and make cities friendlier and more attractive to citizens. However, the term smart has to be connected with—(1) the *design* of services and the city, that must minimize the need to move, (2) the ability to collect and analyze *information* that can help us make decisions, (3) an *infrastructure* that can process information and adapt in real-time, and (4) a mobility ecosystem that can be used efficiently and in a sustainable way. The redesign of city transportation services must be connected with a replanning of the land usage and the proper arrangement of business, commercial, residential, industrial, and other zones. The combined use of a public transportation network, pedestrian, and cyclist zones and parking lots at the city center limits are expected to keep cars away from the city center and reduce traffic (Koska & Rudolph, 2017).

In an effort to bring smart and sustainable mobility as close as possible (i.e., making them overlap in the optimal case), Lyons (2018) defines the concept of *sustainable smart mobility*, which is defined by the requirement for affordable and attractive, but also effective connectivity. With connectivity referring to the need for physical transport of people and goods, a more viable solution will be to reduce the need for physical transport and distances through digital connectivity and city and services redesign. Affordability and attractiveness demand for solutions that reach a wider population base, even people that do not have smartphones or have other cognitive, physical, and financial restrictions, whereas effectiveness examines both economic, social, and environmental aspects and sustainability requests for solutions that maintain the aforementioned characteristics on a long-term basis.

## 18.3 The future of smart mobility and the open challenges

The "Intelligent Mobility Incubator (http://centro.org.uk/about-us/news/2015/intelligent-mobility-incubator/)" was the attempt of the UK Government to focus on smart mobility, building on new technologies, and smarter and greener solutions. The main effort was on the development of mobile applications that are able to provide passengers with real-time mobility information. This was the mainstream viewpoint for the prospects of smart mobility back in 2015. Today, only a few years later, people and governments have realized that smart mobility is more than this. Technology is of equal importance, but new concepts have emerged aside including both the human factor and the current business models. Smart urban mobility is now shaping its future by adopting new energy sources; automation of vehicle control and network monitoring; new models of ownership and use; and IoT and mobile technologies to provide more control and convenience to drivers and passengers. Finally, it seems to have even more opportunities and be profited by city and services redesign that minimize the need to travel around the city or for long distances.

According to Benevolo et al. (2016), smart mobility is emerging in three main axes— (1) the digital city that is built around a ubiquitous network of interconnected devices that allow companies, and organizations to cooperate and share information and services in order to provide citizens with online services that facilitate mobility, (2) the green city that capitalizes on the ecological and sustainable development of cities, and (3) the knowledge city that invests in research and innovation for giving value to transportation data and services. They also recognize the following objectives that are related to smart mobility: (1) reduction of air and noise pollution, (2) reduction of traffic congestion and transfer cost and time, and (3) increase of people's safety.

The smart mobility actions can be grouped in the following major groups:

1. public mobility, which involves all the actions that aim in improving public transport in multiple ways (e.g., by upgrading transport vehicles and adopting electric ones, by introducing automated driving) or improve the quality of public services (e.g., new ticketing systems, or shared ride and taxis).
2. private and commercial mobility that gathers individual citizens and companies under the same initiatives, which are supported by the public administration. Interventions may comprise the development of special vehicles or innovative multimodal transportation plans that affects the citizens' behaviors,
3. infrastructure projects (e.g., bicycle lanes or zones of controlled traffic) that facilitate smart and eco-mobility, and the development of policies for supporting smart mobility. Such policies can provide incentives to citizens that use better fuels, or can be higher taxation to those that use polluting fuels.
4. last but not least are the intelligent transport systems that comprise various applications that improve the resource usage efficiency and allow to better manage urban traffic flows. Applications include parking assistance in defined areas, urban-traffic control, area surveillance and sensing, weather or traffic information and forecasts, etc.

Most smart mobility applications from autonomous vehicles, data collection, and traffic monitoring systems to planning and scheduling applications mainly target private cars and public transport. However, there are more means of transport, such as cycling that can provide useful alternatives (European Commission, 2015). Cycling is a sustainable mode of transport, with proven benefits for individuals and society (e.g., health and fitness, green mobility, etc.). However, it is still underutilized and supported compared to other modes. While it is still considered as an offline activity, there are several research works that consider the potential of smart "*velomobility*" and recommend the use of IoT and ICT for including bicycles in urban transportation planning (Behrendt, 2016; Fishman, 2016). With the use of cycling apps in smartphones, people can collect and share cycling data with other members of the app community as well as with the local authorities, that can use them for improving urban planning and highlighting routes of interest. Smart velomobility also covers electrically-assisted bicycles (pedelecs, e-bikes) and other types of electric two-wheelers, which are becoming quite popular in many cities.

A major change that impacted the popularity of velomobility, especially for city visitors, is the rise of the "*mobility as a service*" concept. In the case of bicycle and e-scooter rental apps, they allow registered users to buy usage credits, geolocate bicycles that are close to them, use them for short distances, drop them at any point and be charged by the usage time. The companies that operate them are responsible for monitoring the status of the scooter batteries, collect and re-charge them and reposition them to popular locations around the city (e.g., outside the metro stations, points of touristic interest, etc.). Last but not least, in order to guarantee the longevity and sustainability of smart mobility solutions and the transition to smarter, faster and safer transport systems, it is important to support the technological advances and changes with policy reforms (Docherty, Marsden & Anable 2018). Transport governance includes the definitions of public policy for smart mobility that considers environmental, economic and social externalities, adjusts the city planning (i.e., the design of the transport network and the land usage plans) and sets the transport-related economic goals. The main objectives of transport governance are to accommodate growth and set the standards for the transport system operation and the desired levels of service. Governance must also support transport innovation and be ready to take accountability for possible risks and prevent infrastructure maintenance.

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Chapter 19

# Big data analytics for intelligent transportation systems

## 19.1 Introduction

One way to perceive data is as a collection of instances that match a certain schema. The schema describes the attributes and properties (e.g., ranges, types, etc.) that instances have. Under this perception, "big data" describes data that are too huge (i.e., they contain large volumes of instances) or too complex (i.e., they have many and complex attributes) and require advanced techniques to process. The sources of big data may vary from sensors and cameras to social networks and from telecommunication networks to financial transactions. In the case of transportation systems, big data can be generated by sensor devices and smart meters that track the moving objects and report their position and status, from wide-area remote sensing systems that monitor the transportation network and supervise all vehicles, or even from social networks and web-based systems. As a result, the decision support system must be able to collect, process, analyze, and redistribute momentarily, complex data in the size of Terabytes to Petabytes, which is impossible for a traditional data processing system to handle.

From a data perspective, the basis for the development of efficient transportation systems is the aggregation of timely and reliable traffic data (e.g., traffic load, speed, density, traffic composition, etc.), which can be collected either by on-site (Leduc, 2008) or by remote sensing techniques (Barmpounakis, Vlahogianni, & Golias, 2016) and usually have to be transferred to a central repository for further processing. Depending on the means of transportation, different techniques are used for data collection, which implies the perception of raw data, an optional preprocessing and the transmission to a higher level network as depicted in Fig. 19.1.

## 19.2 Data collection

### 19.2.1 In road networks

*"On-site" sensing techniques* measure traffic data by embedding "detectors" in the road infrastructure and can be either intrusive or non-intrusive (Zeng, 2015). The former combines a data recorder and a sensor (e.g., pneumatic road tubes,

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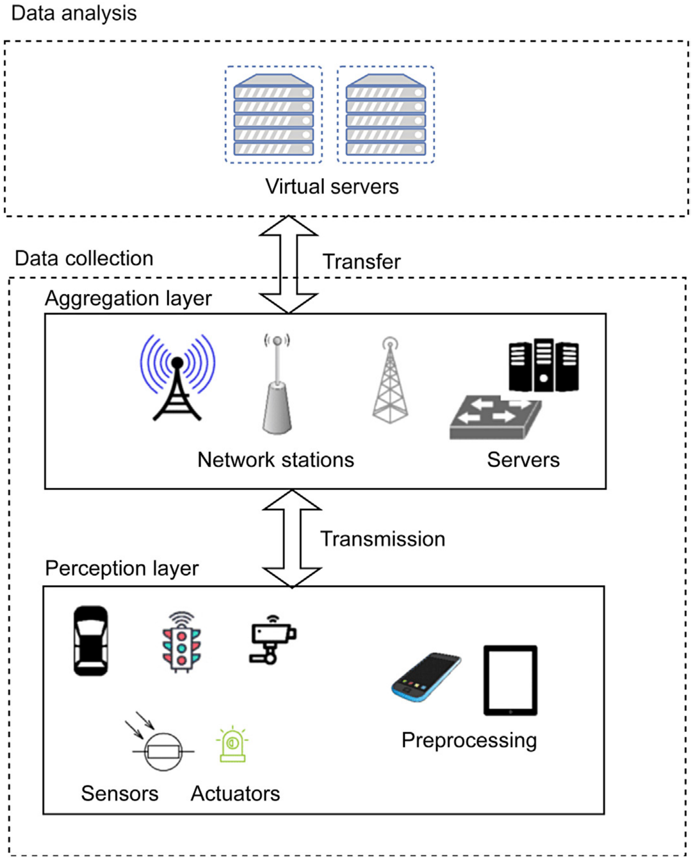


**FIGURE 19.1 The structure of an ITS from the data perspective.**

piezoelectric sensors, magnetic loops). The sensor detects vehicles using pressure or magnetic effects and transfers this information to the data recorder on the roadside. The main problems with such devices are their short life as they are affected by the passing of heavy vehicles and the high cost of application and maintenance. Noninvasive on-site techniques employ local range, but remote, observations. Human observers have been replaced by machines that employ technologies such as infrared, magnetic fields, microwave or acoustic radars, or video cameras. The latter is the most popular on-site nonintrusive technique, in which the road section under consideration is systematically recorded and then analyzed with special image recognition algorithms, that output the traffic load, speed and traffic composition from video streams (Fig. 19.2). On-site observation technologies have lower cost and longer life than invasive technologies, but require advanced processing capabilities in the collection step and faster network connection when data processing takes place in a remote location.

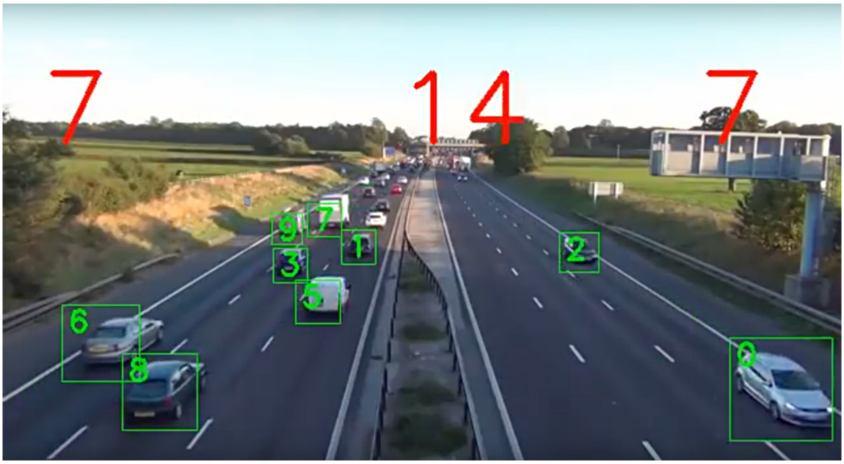


**FIGURE 19.2 Vehicle counting using a video camera.** *(Based on the following source: https://www.youtube.com/watch?v=B5l_3T-ThlA)*

*Remote sensing techniques* become very popular because of the rapid development of automatic positioning systems such as the Global Navigation Satellite Systems, such as GPS, Galileo, etc., that collect data from around the globe and smart mobile phones that deliver the processed information to any individual. The main principle of remote sensing techniques is that vehicles can be spotted at any time either by means of positioning devices or by Bluetooth on mobile phones and/or vehicles. The tracking of vehicles, which are considered as "floating vehicles" in the road network, results in vehicle path data (trajectory data) that depict the vehicle's positions over time. The trajectory data from many vehicles are then aggregated and used to estimate traffic density, vehicle speed, etc. (Seo, Bayen, Kusakabe & Asakura 2017). When a single vehicle is equipped with second-generation onboard diagnostics such as radars, lidars, or stereo cameras, it is possible to act as sensor for its nearby vehicles and collect information for their speed or number, and it is considered an extended floating Car (Barceló, Montero, Marqués, & Carmona, 2010). If some of the vehicles are connected to vehicular ad hoc networks (VANET) they can collect data from their network and report the summary data to the aggregation layer at a higher level (Darwish & Bakar, 2015) using interconnected base stations and access points.

### 19.2.2 Within smartcities

The growing need for a holistic transportation system within the smart city context requires the collective analysis of data from every link of the urban transport chain, including pedestrians, personal (cars, bicycles, and motors), and mass means of transportation.

The techniques employed for data collection from pedestrians and cyclist networks (Ryus, Ferguson, Laustsen, Prouix, Schneider & Hull 2014) do not differ significantly from the techniques described previously for motorized traffic on road networks. However, they face some particular challenges that make their design and implementation more difficult and demanding. More specifically: (1) while vehicles are driven in a limited (and specific) road environment, pedestrians, and cyclists often create their own paths, (2) the limited ability to track—and distinguish between (Tragopoulou et al., 2014)—bicycles and pedestrians create objective difficulties in automatically measuring the transportation network load, (3) bicycle and pedestrian data highly vary by season and are strongly influenced by weather conditions, thus making it difficult to develop traffic flow, prediction models.

The choice of technology to be used to record pedestrian and cyclist loads is usually dependent on two factors (Griffin, Nordback, Götschi, Stolz & Kothuri 2014): (1) whether pedestrians will be measured separately from the bikes or together in a "shared" or "segregated" environment and (2) whether only a temporary snapshot of pedestrian or bicycle trajectories is needed or a continuous monitoring process will be established. The recent advances in video data analysis allow the development of systems that automatically detect, count, and analyze pedestrian (Muthukumar et al., 2015), bicycles, and other vehicle flow using existing traffic cameras (Wei et al., 2017).

The measurement of passenger traffic in mass transportation vehicles can be achieved more easily in relation to the aforementioned cases of vehicles, pedestrians, and bicycles, using the fact that passenger traffic can be counted on the admissions and discharges to and from the mass transportation vehicles at the designated stop points. Such systems are designed for improving public transport experience (Foell et al., 2014) and either aim at providing synthetic-cumulative measurements (e.g. for a line or for the whole transportation system) or quantitative-analytical measurements for a station/stop or a specific time period. An implicit measurement method can be based on ticket cancellations, at the fare collection devices located either in-vehicle or at station/stop entrances. The most advanced technique for measuring passenger traffic is the automatic passenger counter systems that count the persons embarking or disembarking a vehicle using non-intrusive detection techniques, such as infrared detection devices, thermoelectric sensing, video and image processing, etc (Boyle, 2008). Finally, as in the case of vehicles, the use of mobile phones through Bluetooth devices allows the estimation of the number of passengers, but the use of these technologies is still in the experimental stage with few real applications (Handte et al., 2014).

### 19.2.3 In maritime networks

The increasing interest of maritime companies for fleet management and control systems and solutions boosted the interest for vessel monitoring and maritime intelligent transportation systems (Chang et al., 2010). However, it was the introduction of the automatic identification system (AIS) on vessels, in the 1990s, that brought new quality to vessel traffic services (Harre, 2000). AISs are embedded on vessels and comprise a radio transmitter and receiver. The transmitter broadcasts at regular and short intervals, the vessel position and identity as well as metadata about its origin and destination port, so that the radio receivers of nearby vessels can automatically detect them and prevent collisions and seaside stations can collect information about the routes of all the vessels at a short distance.

Although AIS has initially been designed for identifying aircrafts and vessels and improving radar performance, air traffic control and maritime and aircraft safety, it is nowadays used for many more purposes, ranging from vessel tracking (Alessandrini, Mazzarella & Vespe 2018 Arguedas, Pallotta & Vespe 2018) to situation awareness (Varlamis et al., 2018) and vessel emission estimation (Perez et al. 2009). In many cases, the land or near-earth based tracking of AIS is complemented by remote sensing data, such as those provided by radars on satellites and data from the long-range identification and tracking system for vessels (Vespe et al., 2018). The biggest challenge with location data in maritime networks is that although vessels publicly report their positions using AIS, a network of collectors is needed to aggregate the data, to remove redundancies and forward them to a central repository, where they are combined with data from other sources and are analyzed in further. In order to maximize coverage, a network of coastal stations is responsible for the collection and preprocessing of AIS signals that sail near the seaside, and a network of earth stations aggregates image data and AIS data collected by satellites equipped with AIS receivers, as depicted in Fig. 19.3.

### 19.2.4 In air transportation networks

The global airline industry performs more than 38 million flights per year (as of 2018) and the number increases by almost 1 million per year for the last 10 years (https://www.statista.com/statistics/564769/airline-industry-number-of-flights/). The number of scheduled passengers surpassed 4 with an always increasing rate. Advances in IoT allowed collecting a massive amount of data from aircraft, from fuel consumption to aircraft maintenance and weather conditions, which can be used in order to create a better and safer customer experience. Data processing and automation are also evident in other aspects of air transportations (e.g., customer and baggage checking and handling, airport, and in-flight security and safety, etc).

Back in 2002, the Transportation Research Board Committee of the US Research Council (2002) envisioned small aircraft as the future of air transportation. According to the Small Aircraft Transportation System (SATS) concept, small aircrafts were considered easier to pilot, more reliable and safer but were expected to result in tens of thousands of aircrafts being flown between

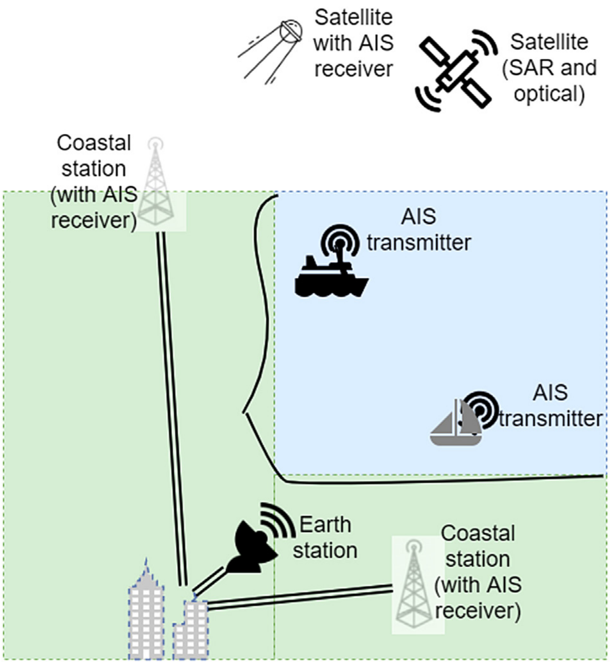


**FIGURE 19.3** **Maritime network surveillance using earth and satellite remote sensors.**

thousands of small airports. The advent of low-cost carriers gave life to secondary airports, strengthened the vision of SATS (Zhang et al., 2017) and transformed the air transportation networks' structure.

The main challenges for air transportation engineers are the alleviation of congestions and delays, the facilitation of access to air transportation services, the safety of aviation, and its environmental compatibility. According to the survey of Sternberg et al. (2017), there is an increasing trend in research toward the application of data mining techniques and machine learning algorithms on data collected from sensors and IoT devices for detecting flight delays.

Unmanned air vehicles (UAVs) are becoming an integral part of intelligent transportation systems, and are primarily engaged in remote sensing activities, such as traffic surveillance (Kanistras et al., 2013). UAVs yet are very sensitive to bad weather conditions and have limited load carrying capacity, so they have not been widely applied to load transportation and logistics. However, there are some works in this direction (Doornebosch, 2016; Maza, Kondak, Bernard, & Ollero, 2009). In the transportation network surveillance scenario, data are collected from radars and sensors attached to the flying vehicles and can be from SAR images on the order of 1–2 meters to local weather data. An advantage of such systems is that they are not fixed in one position and thus can track vehicles and traffic, and thus cover wider parts of the road network. In the case of logistics, multiple UAVs can be planned to move to predefined trajectories

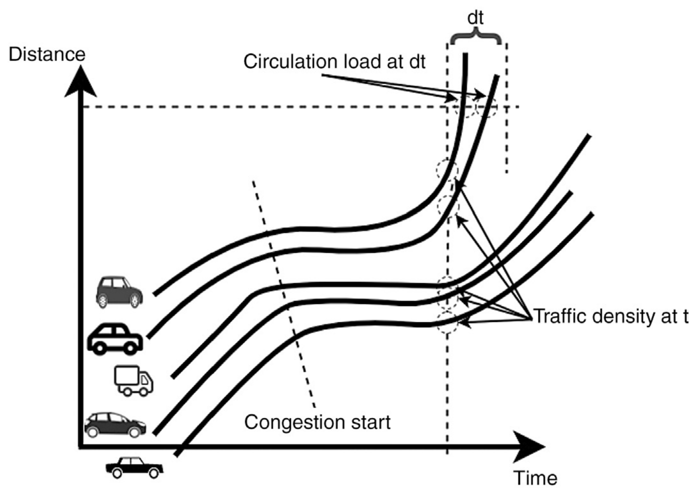


**FIGURE 19.4 An example of a space-time diagram.**

and collaboratively complete transportation missions, always in static and controlled environments (e.g., within factory premises), but are highly sensitive to environment perturbations (Maza et al., 2009). In the same case but in a less constrained scenario, the use of UAVs in last-mile parcel distribution has also been envisioned (Doornebosch, 2016).

## 19.3 Big data analytics

### 19.3.1 Smart cities and road networks

The usual way of displaying collective vehicle data is with space-time diagrams (Fig 19.3 for an 1D space example for vehicles moving in an autoroute), which can then be used to extract information such as: the flow velocity at position x or at time t (determined by the slope of the respective running line), the point acceleration or deceleration at a point of time (defined by the derivative of the speed or the second derivative of space by time), the spatial and time separation between vehicles, the traffic density, the circulation load, etc., as shown in Fig 19.4. Some of the shortcomings of remote sensing techniques are the inability of 2D space-time diagrams to show altitude information that could give extra information such as altitude accelerations, length of a line change and the absence of a "reference point" for each vehicle, which is the actual position of the vehicle sensor system.

The classification of collection techniques can be done either on the basis of the spatial reference level (road section, intersection, etc.) or by the method of recording the traffic data (Leduc, 2008), followed by a detailed presentation of the traditional and modern methods of recovering these data, mainly based on the second categorization.

### 19.3.2 Smart cities and crowd analytics

Ubiquitous sensors can be part of many intelligent processing and decision support systems, ranging from tracking and monitoring applications to environment and human sensing (Bačić, Jogun & Majić 2018). According to the interesting survey of Kaiser, Lwin, Mahmud, Hajializadeh, Chaipimonplin & Sarhan 2017, transportation data are one of the main data sources generated by the ubiquitous sensing of citizens in smart cities. At the same time, crowd data from other sources, such as mobile phone network data, RF and IR-based data, and satellite and video data can be exploited in order to detect traffic-related events and adjust the public transportation schedules accordingly (Djahel, Doolan, Muntean & Murphy). Modern traffic management systems can also be profited from crowd analytics since they can process heterogeneous data of high volume and (1) keep useful information in real time and (2) statistical data for further analysis for longer periods.

Since the amount of crowd data that is collected from a sensor network can be huge, it is almost infeasible to process it in its entireness and to keep it collected for very long periods. In order to increase the efficiency of this process, it is necessary to filter sensor data in real-time (Mohamed & Al-Jaroodi, 2014) and keep only useful summaries or values, such as hourly means and deviations, very low or very high values, etc. and feed these aggregates to a data analytics system as depicted in Fig. 19.5.

As depicted in the figure, the main sources of data are citizens, who either directly—through smartphones and wearables—or indirectly—through smart vehicles, produce geolocation data in a streamlined fashion. The data are collected and preprocessed on the edge, which means that the data collection nodes have the necessary processing power to filter out non-useful data and keep only values of interest. Such stream processing capabilities can be achieved with software explained later in this section. Only useful data are aggregated on the cloud servers, where the main processing and data archiving takes place. Using predefined rules and limits, the sensing system will be able to detect deviations and outliers in real time (e.g., road traffic, or passenger loads) and raise alerts. At the same time, it is possible to gather useful long-term statistics and provide

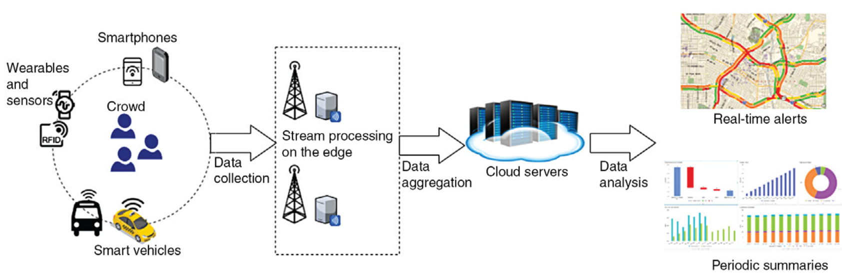


**FIGURE 19.5 Crowdsensing for ITS in smart cities.**

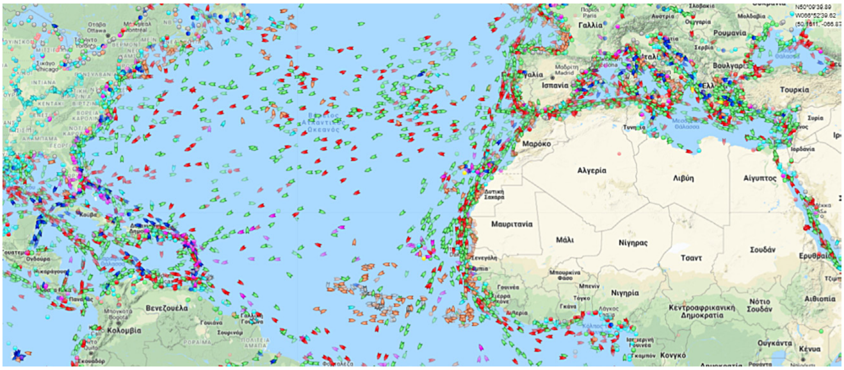


**FIGURE 19.6 Real-time vessel positioning from the MarineTraffic platform.**

the decision makers with visualizations and summaries that can help them redesign the transportation network or the related city services.

### 19.3.3 Maritime network analytics

The need for monitoring maritime networks and identifying the routes and positions of ships has become a necessity in the rapidly expanding maritime sector (Ducruet, 2017). The AIS has been designed for supporting port authorities in achieving better maritime traffic control, but soon became the key asset for companies that perform maritime transportation network analytics.

The MarineTraffic platform (https://www.marinetraffic.com/) is the most popular vessel tracking service that collects AIS data using a world-wide network of shore-based stations. Stations collect and preprocess AIS signals (for missing values, errors, and redundancies) and forward the result to a centralized processing server for further cleaning, postprocessing, and visualization. The platform provides real-time information on the ship's position (Fig. 19.6) and information on arrivals and departures from ports. A lot of data analytics projects and data mining applications have been developed on top of the historically collected data, ranging from the automatic detection of events (Varlamis et al., 2018, Kontopoulos et al., 2018) to the prediction of vessel position (Valsamis, Tserpes, Zissis, Anagnostopoulos & Varvarigou 2017) and time of arrival to the port. VesselTracker (https://www.vesseltracker.com/) is a similar aggregator of AIS data that offers its registered users information about ship positions, ship metadata, reports, and statistics. The site also provides historical AIS data, weather forecasts, and ship alarms via email, SMS, or phone. The MariWeb platform (https://imisglobal.com/mariweb/) developed by IMIS Global provides tracking services for ships using a similar data collection and processing architecture.

The analysis of big maritime data can make the industry more intelligent, in a multitude of ways: first, by giving deeper insights on essential maritime

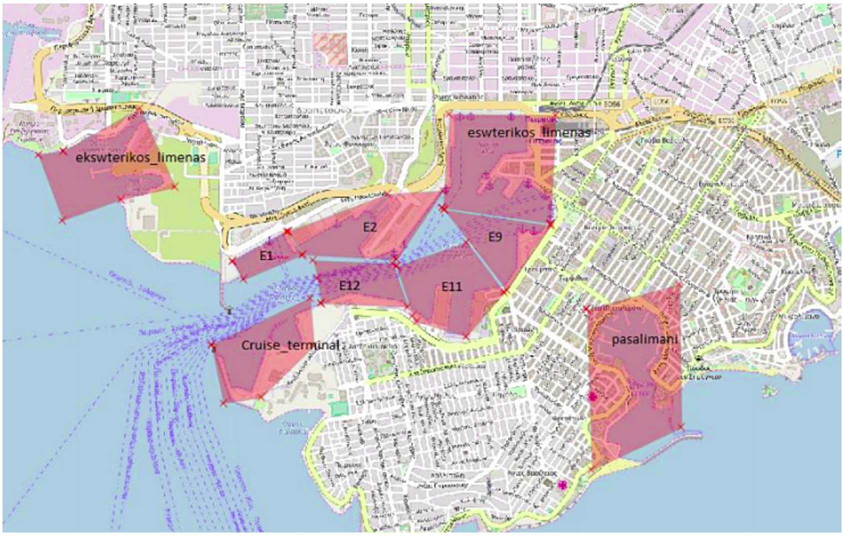


**FIGURE 19.7** **An image of the traffic load for the marinas of a port.**

operations such as route planning and fleet tracking and management, which in turn can drive more successful strategies; second, by using predictive analytics it is possible to know in advance instead of guessing and thus to improve the quality of decisions and create more successful business models; third by connecting data and information from various sources and developing a new culture of data sharing (or data business).

What can be interesting from the data analysis point of view is the detection of outliers, or simply deviations from the norm, so it is important for such applications, first to extract an abstracted naval transportation network, that contains the main nodes and routes that connect them and then to use for detecting whether a ship is moving on a previously known path or deviates from its route (Varlamis et al., 2019). Another interesting output refers to the extraction of aggregate statistics about the usage of maritime infrastructures (e.g., ports and marinas) and the delays they introduce to the transportation network (Fig. 19.7).

## 19.3.4 Aircraft analytics

Over the years, the air travel industry has managed to offer travelers a fast, comfortable, and affordable solution for long-range travel and thus became highly popular among travelers. This has led to an apparent increase in air traffic, which in turn led to the rise of long aircraft delays both in the ground and in the air and major economic and environmental losses. In response to growing concerns about flight optimization the use of big data collected by aircraft positioning systems and data collected from sensor systems embedded in aircraft.

In parallel, there is active research into the aviation industry to find techniques to predict flight delays with precision in order to achieve optimization of flights and minimize delays.

The process of data collection and data preprocessing does not differ from that of maritime networks. However, the main differences are in the type of analysis and the output it produces. One major type of analytics is centered around arrivals and departures in the airport, for airplanes and passengers and is broadly described with the term "Airport Analytics." The overall aim is to reduce waiting time and this is mainly based on the ability to predict an airport's flow. Constant measuring and monitoring of passenger and plane throughput KPIs help in evaluating airport efficiency. In general, a data analytics platform that captures multiple aspects of airport operations and reports on the actual performance at any moment is the main step in developing intelligent aviation transportation systems.

Based on the same predictive analytics of passenger and airplane flow, it is possible to develop a business intelligence solution at Carrier Company or industry level. For example, a company can have better information on the position of its aircrafts, of the delays and passenger loads at the different airports and can better schedule and plan their flights in order to maximize the number of passengers per flight, reduce expenses on fuel, minimize baggage, and passenger processing time while on ground (Nogueira, Aguiar & Weigang 2014). When it comes to air cargo industry, intelligent decision support systems rely on big data collected from airport, rail, and other transportation networks in order to minimize delays and empty space in cargo transportations (Döppner et al., 2018).

## 19.4 Big data processing systems for intelligent transportation

The work of Oussous, Benjelloun, Lahcen & Belfkih 2018 provides a useful summary of technologies for big data analytics in any domain. The main tasks that are supported by such software and are critical in big data processing are: (1) data management, (2) data cleaning, (3) data aggregation, (4) data balancing, (5) data analytics, and (6) data stream processing. From their analysis it is clear that the utilization of big data in the case of intelligent transportation systems can follow two different processing paths: (1) the process of *streaming data* and the extraction of useful information on the fly and (2) the *analysis of historical data*, which is aggregated on data warehouses and serves for creating business intelligence and supporting decision making (Chowdhury, Apon & Dey 2017).

The scalability of solutions is achieved by distributing the processing load to multiple nodes and by implementing parallel processing algorithms. The two main subcomponents of the Hadoop platform (https://hadoop.apache.org/)—the Hadoop Distributed File System (HDFS) for distributed data storage and the MapReduce framework for distributed data processing—allow parallel

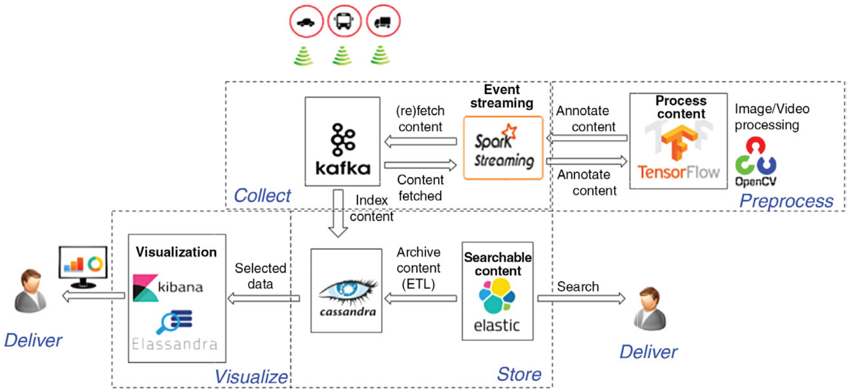


**FIGURE 19.8 An overview of an architecture for stream processing and analytics of transportation data.**

solutions to scale up to bigger data sizes. When a database is needed for storing data, HBase (https://hbase.apache.org/) is the distributed nonrelational database that operates over HDFS and adopts a simple key/value data model that allows us to scale out horizontally in distributed nodes. In the same pipeline, data querying and data analytics are served by open source platforms such as Pig (https://pig.apache.org/) and Hive (https://hive.apache.org/). More generic solutions that store data on Apache Cassandra (http://cassandra.apache.org/) and visualize collected data using Javascript technologies are also used to replace the data warehouse part of the architecture.

When it comes to data streams, it is important to preprocess data in real time, instead of batch-processing data for a longer period. Apache Storm (http://storm.apache.org/) an open-source distributed system for handling real-time data processing. The combination of Apache Kafka for data orchestration and Spark Streaming it is also possible to process live stream data. A cluster of Kafka nodes collects data from the IoT and serves it to the Spark streaming nodes into microbatches, which can then be processed, using machine learning or AI techniques (Fig. 19.8). The result of this processing is then stored back to the data warehouse for supporting data analytics (Amini et al., 2017; Figueiras et al., 2018; Zhu et al., 2018).

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Chapter 20

# Personalized mobility services and AI

## 20.1 Artificial intelligence in transportation

*Artificial intelligence* (AI) is a simulation of human intelligence processes by machines and depending on the problem complexity either aims to support or to replace human intelligence. The increasing interest of researchers and companies for artificial intelligence solutions brought AI-driven development among the top-10 strategic technology trends for 2019 (Gartner's top-10 strategic technology trends for 2019: https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019/). Although AI is not new, and its history begins back in the 1950s, there have been dramatic changes in the last 10 years, which is mainly due to the rise in *computing power* and *available data*. These two components are the main enablers that allow AI algorithms to control smart services and automate complex operations.

Almost all the major cloud vendors invested in AI in order to create a new market of AI solutions as a service, with applications in many domains.

IBM launched Watson (IBM Watson AI platfotm: https://www.ibm.com/watson) as a service in an attempt to attract new customers and allow third-party companies to develop AI solutions. IBM Watson started as a question-answering system that was able to understand natural language and respond with facts from a huge knowledge base and evolved into a suite of enterprise-ready AI services, applications, and tools. According to the IBM, Watson allows companies to accelerate research and discovery, enrich their interactions, anticipate, and preempt disruptions, recommend with confidence, scale expertise and learning, detect liabilities and mitigate risk and consequently frees employees from repetitive tasks and empowers them to focus on the high-value work that is critical for an enterprise. Question-answering systems that extract facts from company documents, virtual assistants that respond to online customers and chatbots and smart readers of complex documents (e.g., contracts) are among the tools offered by the Watson suite. In the domain of mobility, IBM Watson has powered with AI technology the autonomous vehicle of Local Motors, Olli, a fully electric car that can be 3D printed and can hold up to 12 people (English, 2016).

Microsoft's Azure AI (Microsoft Azzure AI platform, https://gallery.azure.ai/) offers a suite of algorithms, solution templates, reference architectures, and

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design patterns that allow companies to develop custom AI solutions to their problems. Several experiments are showcased in their website including image classification and recognition, outlier detection and time-series predictions as well as an example that uses regression algorithms to score parking availability in the city of Birmingham, UK, using open data. The domains of application include among others, retail market (sales forecasting, predicting customer churn, and pricing models), manufacturing (predict equipment maintenance, forecast energy prices), banking (predict credit risk and monitor for online fraud), and healthcare (detect disease and predict hospital readmissions).

Salesforce's solution to smart CRM is called Einstein AI (Salesforce Einstein platform https://www.salesforce.com/products/einstein/overview/). The platform uses machine learning and AI to support faster decision making for managers and increase the productivity of employees, and personalized recommendations that increase customers' satisfaction. With a combination of the AI tools which are available as a service, companies can build solutions that discover significant patterns and trends in sales data, can understand their customers by learning which channels, messages, and content they prefer and allows every employee to have instant access to smart insights and business AI-powered analytics.

C3 AI develops solutions for the operators of transportation, logistics, and travel companies, which comprise IoT analytics and predictive machine-learning models. For example, the C3 predictive maintenance solution, which is a part of the C3 AI suite, provides estimations related to the risk of failure of various vehicle equipment and recommends maintenance actions that can prolong their safe operation. It is, in essence, a supportive tool for fleet owners with monitoring and preventing capabilities that guarantee optimized fleet performance. In addition, C3 AI provides data analytic services for sales and demand data and allows enhanced demand forecasting, and increased customer service. The full list of applications (C3 AI solutions, https://c3.ai/products/c3-applications/) comprises sensor health algorithms, inventory optimization, facility energy management, supply network, and CRM solutions.

Google AI (Google AI platform https://ai.google) brings together hardware, software, and AI, and makes devices faster, smarter, and more useful. It offers Cloud AutoML, an online solution that allows developers, researchers, and businesses with limited AI expertise to build their own custom models. Google's parent company Alphabet runs several transport-relevant projects and encompasses a host of other subsidiaries called "Other Bets," such as (1) Waymo, the self-driving car initiative, (2) Sidewalk Labs, the urban innovation organization, and (3) Project Wing, which is developing an autonomous delivery drone service. The combination of cloud computing and IoT-edge computing (Google's IOT edge computing https://cloud.google.com/iot-edge/) allows the training of complex models on the cloud and the deployment of the trained models at the edge for faster real-time prediction. Thus intelligent technologies that prevent and avoid collisions, detect driver's distraction and provide alerts, collect and analyze traffic information, and give route alternatives can be easily integrated with existing infrastructure and embedded on existing and future vehicles using IoT devices.

Since 2015, Nvidia invests in hardware acceleration of deep learning architectures, for providing autonomous car and driver assistance functionality (Oh & Yoon, 2019). The Nvidia Drive AGX open autonomous-vehicle computing platform collects data from various sources such as cameras, lidars, ultrasonic sensors, and radars. Then, processes the data in order to get a 360-degree understanding of the surrounding environment in real-time, detect the vehicle location on the map and within the surrounding area and be able to plan the next movement safely. This high-performance computing platform is energy-efficient and able to develop safe and highly responsive self-driving models. TuSimple (TUSimple website https://www.tusimple.com/) is a Chinese startup that uses Nvidia GPUs and the cuDNN CUDA deep neural-network library to power its driverless trucks, that promise to autonomously transport products in a depot-to-depot basis.

## 20.2 Smart mobility services

Back in 2015, a report by the Texas A&M University has reported that the delay in commute times in the United States because of traffic in peak-hours is a bit more than a full work week per year, and results in $160 billion in lost productivity. Artificial intelligence can be a powerful tool for reducing commute times even for multi-modal trips that combine car, public transportation and walking, or for handling unexpected delays that are due to accidents, road works, or weather conditions. According to the One Hundred Year Study of Stanford for Artificial Intelligence and Life in 2030 (Stone et al., 2016) data availability and connectivity allowed real-time sensing and traffic prediction applications, are expected to boost peer-to-peer ridesharing cases and self-driving cars. Also, the adoption of autonomous transportation is mainly based on peoples' trust in the physical hardware's safety and robustness and in 2030 is expected to expand from cars and trucks to flying vehicles and personal robots. According to the same study, the development of personalized transportation services that will be based on peer-to-peer interaction and car-sharing will minimize the need for car ownership and will convert the car from asset to service. The result will be the development of the "car as a service" concept.

AI services have also be used by companies that provide *ridesharing* services at a large-scale, such as Uber and Lyft. Uber's price optimization algorithm uses location and rides' data from the network of drivers and clients and historical data in order to predict rider demand and ensure that sharp price fluctuations, which aim to regulate rider demand, will be no longer be necessary. Uber's machine learning models are also able to predict estimated meal delivery times on UberEATS, optimal pickup locations, and detect fraud. On-demand transportation services use AI algorithms to match drivers to passengers by location and reputation. They also run pricing algorithms that dynamically adjust ride prices to balance the demand and offer equilibrium. Carpooling and ridesharing services such as Zimride and Nuride allow passengers to share routes and costs but they have limited traction so far mainly because they still do not integrate with the public transportation services (Kamar & Horvitz, 2009).

Personalized mobility can be achieved by a combination of *adaptive public transportation* and personal or shared rides. With the help of data analytics and predictive algorithms, it would be possible to provide accurate real-time information for the public and shared transportation to passengers. In combination with empty autonomous vehicles, it would become feasible to reduce passenger waiting times and provide door-to-door personalized transportation services. Shanghai Bus, is a public transportation project developed by the Shanghai Municipal Transport Commission, which provides passengers with real-time information on the positions of all public transportation vehicles in the bus, train, and metro networks using an Automatic Vehicle Location system. It also uses prediction algorithms to provide information about the total travel time and possible delays or the waiting time at stops. This allows smarter algorithms to be developed that will allow passengers to arrive at stops only a few minutes before the vehicle, and the vehicle to accelerate when needed in order to serve the passenger needs (Ma, Lin, Chen, Zhang).

*Fully-autonomous cars* are still a few years before mass production and their use is now only visioned on highways that provide a more controlled driving environment. However, in April 2018 California Department of Motor Vehicles passed regulations that allow for the public testing and deployment of autonomous driverless cars. Self-driving trucks seem to be a more realistic project especially because they can operate in closed environments (e.g., in the premises of a factory) or perform a repetitive task. Finally, driverless buses (usually with an extra driver for safety reasons) appear in many European countries. They usually move in predefined paths but use sensors, cameras, GPS, and AI models to analyze visual input for detecting and avoiding obstacles and safely carry passengers to their destinations.

Smart *route planning* is one of the first applications of AI in transportation networks, with many algorithms that seek for the optimal route between two points by considering the network load or throughput (Bast et al., 2016). Multimodal route planning that combines public transportation, own vehicles, and ride-sharing is a much harder problem that needs advanced algorithms, past data, and prediction models in order to evaluate multiple criteria in tandem. Google *Maps* is a vivid example of an AI-powered application that assists drivers to reach their destination in the fastest possible manner, since they crowdsource location data from Google-enabled smartphones, analyze the vehicles' movement speed and provide real-time estimations of traffic. They can also incorporate reports for road works and accidents. Graph-mining algorithms allow Google AI to suggest the fastest route to each individual driver.

*Personalized traffic control systems* that interact with lights at intersections to respond to individual vehicles is another AI-powered solution that is expected to decentralize and reduce traffic flow. Surtrac (Surtrac, Intelligent Traffic Signal Control, https://www.rapidflowtech.com/surtrac) by Rapid Flow Technologies is such a system that has been designed for urban areas and is able to adapt in real-time to changing traffic by optimizing traffic flows every second. Surtrac yields improvement over conventional traffic signal timing by reducing travel times by 25%, waiting time at signals by 40%, stops by 30%, and emissions by 20%. It also optimizes for pedestrians, cyclists, transit, and connected vehicles, thus reducing delay for everyone (Smith et al., 2013). The system architecture comprises sensors located at the intersection, a scheduler that allocates green time to the incoming vehicle or pedestrian flows, and an executor that implements the selected schedules by communicating with the traffic lights in the intersection and in neighboring intersections.

The use of onboard diagnostics (OBD) systems has increased the vehicle's self-diagnostic and reporting capability and has become a critical part of motor vehicles. Although the initial purpose of OBD sensors was to monitor the vehicle's health and to lead to early diagnosis of faults or risks, they have been recently extended with more sensing devices that collect information for both the vehicle and the driver status and behavior. *Personalized driver assistance systems* (DAS) comprise biosensors, wearable devices, and onboard cameras that provide real-time data on driver's vital signals. A combination of data mining algorithms trained on multiple drivers' historical data and real-time information from each driver allows to early detect driver's drowsiness, blackout, level of fatigue, distraction, or risk (Brodsky, 2018). For example, using a camera, it is possible to capture the driver's face every few milliseconds, then extract several image features (as well as any other biometric features, such as heart rate, blood pressure, etc.) and fed them to a pretrained classification model. The model will be then able to detect whether the driver is awake or is close to falling asleep. In a slightly different example, the reflex of the driver in the road conditions (e.g., the speed of braking or wheel-steering) can be recorded with car embedded sensors and fed to a model that detects whether the driver is tired and needs a break or not. The data can be sent to a processing node in the cloud (cloud-computing model) if the response is not time-critical, whereas, in time-critical cases, the processing must be performed in the car. This has become feasible with powerful GPU-enabled processors embedded in cars, or in the network provider's backbone (edge and fog computing models), which offer huge processing power in the edges of the network (Mane & Agarwal, 2017).

Apart from assisting in driving the car, the DAS aims to *increase the comfort and sense of safety of the driver*. This is usually achieved with the use of sensor data and a personalization module that adapts the vehicle's performance to the driver's preferences (Butakov & Ioannou, 2015). The personalization builds on three main pillars—security, safety, and comfort (Martinez et al., 2018). Safety aims at preventing accidents that may due to a strange driver's status, security aims to protect the vehicle from theft or other intentional damage, and comfort aims to adapt the car parameters (e.g., car seat and mirrors position, cabin temperature, etc.) to drivers preferences. The personalization mechanisms monitor driver behavior at all moments and learn by observation. DAS systems also learn the road conditions from other drivers and the driver's behavior through continuous monitoring of his/her actions. Using the drivers' behavioral model on events such as turns (Karaduman & Eren, 2017) or lane changes (Vallon et al, 2017) they are able to provide an autonomous driving behavior that perfectly matches the driver's behavior and thus increase the driver's trust to the autonomous system.

## 20.3 Conclusions and open issues

The use of machine learning and AI algorithms on data collected by multiple sensors attached to drivers, vehicles, and the road network allows new smart solutions to be developed. It also attracts major software development, sensor, and computer hardware companies that promote solutions as a service and in collaboration with car manufacturers add many assistance accessories to the drivers. On the other side, as new smart mobility services emerge and AI applications are taking the role of drivers or become co-pilots, several new issues arise. The backbone of the connected autonomous vehicles network becomes a space for hackers to attack or exploit, so network providers must consider data encryption methods and anonymization mechanisms that will protect drivers' sensitive information and will increase the network safety and security (Bellet, Cunneen, Mullins, Murphy, Pütz & Spickermann 2019). The expansion of ride-sharing companies also raises policy and legal issues, such as competition with taxi services and the need for a regulatory framework.

Shared transportation and personal rapid transit are expected to replace or complement public transportation. The expansion of personalized solutions will lead to an explosion of wasted transportation capacity, which must be prevented (Chebbi & Chaouachi, 2016). Multi-objective optimization algorithms must be developed to cope with the redistribution of empty vehicles and minimize the use of empty vehicles.

Finally, as autonomous driving systems are taking and place of driver-assistance systems, several ethical questions arise, which refer to how autonomous cars will act in critical decision-making situations that involve humans, such as when they have to choose between actions that will result to human injury or death, and they must decide who to put at risk (Lin, 2016; Bonnefon, Shariff & Rahwan 2019).

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Chapter 21

# Integrated mobility for smart cities

## 21.1 Introduction

The trend in urban and national planning is the development of intelligent—also known as smart—cities that implement smart systems to bring benefits at all levels of planning. At the beginning of our century, smart cities were identified as digital cities that incorporated several technological advancements into their infrastructure and begun to consider the participation of the citizens in the city development. This model of participatory governance took advantage of economic growth and used technological advances in order to ameliorate the quality of urban services, improve their efficiency and effectiveness, and increase city competitiveness.

The need for better life quality, especially for those that live in large urban centers is more evident today than ever before. Nowadays, more than half of the world's population is in urban centers and by 2050 urban citizens are expected to reach 68% of the world's population (United Nations' 2018 Revision of World Urbanization Prospects. Available at https://population.un.org/wup/). This inflation of urban population along with the debt crisis, which has become a permanent feature of the developed economies of Europe and America, and the advent of several dynamic regions and emerging economies from Asia, give rise to a new generation of cities and a new model of design that combines knowledge and innovation. Modern urban centers are complex ecosystems, with a particular concern about the quality of life and the sustainability of any development plan. The increased need for better health care and public transport, better use of energy and protection of the environment, for increased security and improved public services, makes the population and public authorities in large urban environments aware of technological solutions that can facilitate their living. Web-based applications, content management platforms, and broadband infrastructures are a few advances that can be useful for the citizens and authorities of large cities.Turning a city into "smart" can be a strategic move for confronting issues related to population growth in large cities and the quick urbanization of other areas, and to improve environmental management, economic and social attractiveness (Aisopos, Litke, Kardara, Tserpes, Campo & Varvarigou 2016). The latter is becoming more and more important and is based on a large set of

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services provided to citizens. The term "smart city" was introduced in the 1990s to emphasize the innovative use of technology for supporting sustainable urban development (Gibson et al., 1992) over the globe. Over the last decade, technology-related companies (e.g., Cisco, IBM, or Siemens) use the term to describe "complex information systems, integrated into urban infrastructure and services such as buildings, transport, electricity, and water distribution, as well as public safety"(Harrison & Donnelly, 2011). The concept of city intelligence may include multiple aspects such as agility, networking, sustainability, knowledge-driven, innovative, digital, etc. (Jucevicius & Liugailaite-Radzvickiene, 2013). Based on the analysis of (Giffinger, Fertner, Kramar & Meijers 2017) *Smart Mobility* is among the list of goals of a smart city, which also comprises concepts that relate to smart economy, people, governance, environment, and living in general. According to the same study, the main smart mobility objectives relate to local and international accessibility, availability of ICT infrastructure, and sustainability of transport systems.

The development framework for smart cities is three-tiered and begins with the *smart city design* that includes: (1) description of the city, its functions, its problems and the challenges it has to deal with, (2) selection of an innovation ecosystem, and (3) selection and creation of digital space, necessary technologies, applications, and systems for smart environments. The second tier of *strategy selection* focuses on the processes of innovation and the knowledge functions that will solve problems in the physical, institutional, and digital space. Finally, the third tier *implements* and supports the selected strategy by (1) finding solutions to the respective problems and developing applications for the city (Tzoumas et al., 2016), (2) developing a business model for the sustainability of services and, measuring and evaluating the implementation of the strategy, using indicators, comparison of results, and documentation of spatial intelligence.

The intelligence of a city or area in the transport sector relies on the application of advanced technologies in the field of electronics, communications, computer, control, and tracking to all modes of transport to increase safety, efficiency and to serve all real-time travel. Innovative solutions for transport meet the growing needs of citizens in terms of the mobility of new services, such as car-sharing, bicycle-sharing, or smart ticket solutions. ITS is key to achieving public policy objectives, supporting urban mobility planning and, offering tailor-made measures tailored to the various urban mobility scenarios.

## 21.2 Smart mobility applications

The applications of ITS when it comes to smart cities can be divided into five major categories as follows:

- Information systems for travelers and drivers. The information includes navigation instructions, timetables, notifications about congestions, real-time notifications for accidents, weather, or even road repair works.

- Transport management systems, which allow traffic management by providing remote control to traffic signals, ramps, electronic message signs, etc.
- Smart pricing systems that control toll payment and provide more flexibility with congestion pricing, pay lanes (EXPRESS), and pricing based on the distance traveled.
- Systems that provide analytical information about public transport. For example, position reporting systems on trains and buses and real-time information to passengers through smartphone apps, or telematics applications in stops and terminals.
- Full integration of intelligent systems for communication (vehicles with or between vehicles), on assets by using sensors in vehicles, roadside, traffic lights, and other vehicles.

Advanced traveler information systems may also include applications that travelers can use before commencing their journey in order to get informed about the actual conditions. Such applications use data collected from smartphones and city sensors and provide information about road traffic, alternative routes, and more. Advanced transport management systems include traffic control and incident management systems, which aim to regulate network traffic and avoid network bottlenecks in a preventive manner by analyzing real-time data and notifying all the engaged bodies (e.g., transportation operators, police, citizens, etc.). Advanced pricing systems usually prioritize environmental protection but also drivers' comfort and aim to reduce the waiting times in tolls, to better control the use of highways and regulate the number of vehicles in the city centers or other areas. Figure 21.1 depicts the main information and other smart services of an integrated mobility environment for smart cities.

Many cities have already made progress in integrating intelligent systems in such areas. Singapore was the world's first major city, to employ smart pricing in order to keep vehicles away from the city's central business district, back in

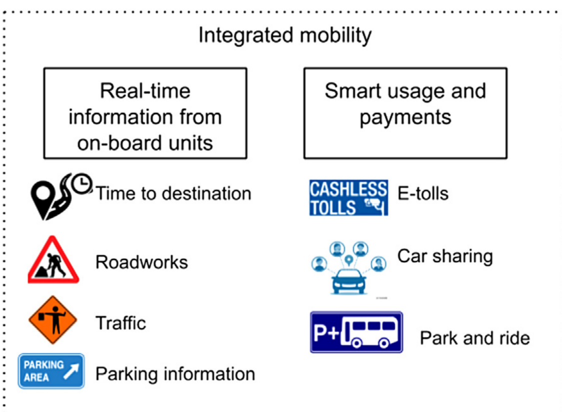


**FIGURE 21.1** **Information and other services of an integrated mobility plan.**

1975. London implemented a similar plan in 2003 and extended it in 2007. With additional fee charges on peak traffic hours they achieved huge reductions in traffic, accidents, carbon dioxide ($CO_2$) emissions, and increased public transit usage. Stockholm, New York, and many other big cities followed this paradigm.

In the case of applications that target means of public transport, publicly accessible information is collected, aggregated, and visualized either in real-time or periodically in order to provide insights on the use and efficiency of the public transport network. Finally, full integration requires data to be collected and analyzed in order to provide flexibility in traffic management as well as to allow better planning by the authorities.

## 21.3 Benefits and challenges

The benefit from smart mobility applications can be maximized when all existing modes of transport and all the available data are incorporated in a single strategy that performs multiple tasks at the same time (e.g., adjust routes, increase frequencies, raise alerts, etc.) in order to offer more transport alternatives to citizens and reduce accidents and delays. The result of such strategies will be an integrated mobility framework that will provide better functionality and help all citizens improve their quality of life.

The integrated mobility framework will comprise more than just a set of discrete technologies and will provide many benefits for citizens. The main benefit categories are as follows:

- increased security,
- better operational efficiency and less traffic,
- easier and more informed mobility,
- environmental care, and
- increased productivity and economic growth.

Integrated mobility systems contribute significantly to the reassessment of vehicle safety by assisting drivers to prevent vehicle collisions. In addition, they maximize the capacity of the infrastructure with smart routing, thus reducing the need for additional motorways. For example, real-time data usage allows smart traffic lights that improve traffic flow and smart bus schedules that dynamically reallocate buses in areas with few passengers. They also reduce travel time for users, reduce vehicle fuel consumption and indirectly reduce carbon dioxide emissions and improve the economic situation of a whole country.

Many cities around the world face transportation-related challenges such as increased traffic congestion, security concerns, and aging infrastructure, lack of funding and increased environmental impact. For this, they started implementing smart solutions that provide improved mobility and a more efficient transport network. By improving the operational performance of the transport network, enhancing driver mobility, and ease of movement, they increase productivity and economic growth. Japan invests enormous amounts ($700 million a year) for the development of ITS. South Korea invests $ 3.2 billion per year for the proliferation of ITS and its regulatory plan that uses four models to control the signal transmitted by vehicles and to adapt traffic, collect real-time traffic information, manage public transport, and record violations in cities.

## 21.4 The future of Integrated Mobility

The technological advancements of the last decade have redefined smart cities, which are now driven by the 4th industrial revolution. Smart technologies are an integral part of the most critical city services including administration, safety, real estate, and transportation, which now become more intelligent, interconnected, and efficient. The same principles have shaped the concept of smart and integrated mobility (Lee, Hancock & Hu 2014).

### 21.4.1 The new features

The need for *personalized solutions* is more evident than ever before and people rely more and more on push notifications and offers. Mobility-as-a-Service emerges as a new solution for travelers that need personalized door-to-door journeys. Population aging is adding to this direction since aging seniors are more dynamic but have reduced mobility. To address such issues, private companies such as Uber and Lyft have launched their self-driving car pilots that can pick up passengers in big cities, whereas Waymo operates its own autonomous minivans on public roads in Arizona. In a more expensive solution Dubai Future Accelerators design Autonomous Air Taxis, which are expected to become the world's first "self-flying taxi service."

Internet access and *connectivity* are considered public goods and become the main means of communication. *Multi-modal transportation* and the *sharing economy* are becoming the next standards for mobility and are adding new options for smart mobility schemes. Autonomous driving in public transportation is already in progress. EasyMile tests driverless electric buses since 2015 in more than 14 countries around the world, PostBus in Switzerland launched an autonomous bus experiment in 2017 and Transdev in collaboration with Delphi Automotive started a project of autonomous public-transit shuttles in France. The car-sharing market keeps increasing at a fast pace and according to the World Economic Forums is expected to affect the self-driving cars market too. Although train and public transportation are still the runner ups of own car for long and short distance travel respectively, the interest for self-driving cars is expected to boost own transportation and increase traffic.

The raising need for *digital and physical security* is another factor that will affect the future of mobility. Security is among the core services for improved passenger experience and the use of AI assistive technologies, of driver alerting systems, etc. aims in this direction.

### 21.4.2 Use cases

Smart and integrated mobility is expected not only to affect life in big cities but also will have a major impact on city planning and real estate. According to OECD (Martinez & Crist, 2015), the use of carpooling and self-driving cars that can be shared among citizens could reduce traffic. The report examines the expected results from the use of shared self-driving vehicles in the city of Lisbon, Portugal. It proposes a combination of self-driving cars that can be shared by more passengers, atomic vehicles that carry passengers in a sequential manner and public transport in order to provide the same travel and commute times like today. The study concludes that: (1) 10% of today's cars can be removed, (2) the total kilometers of car travel will increase because several bus routes will be replaced by smaller car trips, (3) the total traffic will either increase if more atomic vehicles are used or decrease up to 65% if larger buses are employed, (4) the need for parking spaces will be reduced since cars will be almost always in use, (5) the absence of public transport will dramatically increase the number of shared and atomic cars, so public transport is more than necessary for the success of the tested scenario.

With the use of smart mobility, city planners, and companies have developed transportation plans that keep life in cities at a high-quality level and do not sacrifice the land use. Google's Sidewalk Labs announced a promising project in Quayside, Toronto that combines modern urban design and technology to develop sustainable, affordable, and people-centered neighborhoods (Galang, 2017). According to the plans, access to the neighborhood will be given only to pedestrians, cyclists, and shared and self-driving vehicles, whereas a "'transition zone" will allow people to travel beyond Quayside. Adaptive traffic lights will prioritize pedestrians at central intersections, the tunnels, or utility channels layer will serve for city services, the street layer will be the basis for citizens mobility and the data layer will combine sensors and software for supporting smart mobility services.

The city of Songdo (NewCities, 2018), near Seoul, Korea, constitutes another major smart city and smart mobility project that started in 2005 and until 2022 aims to create a huge trading hub for southeast Asia. The project employs technological infrastructure by Cisco Systems, with sensors throughout the city to monitor everything, from temperature to traffic and provide city analytics and a fully equipped lab the "IoT Cube" where businesses and startups can pilot smart mobility solutions combining Wi-Fi, fog, and edge computing. However the cost of living still hinders new citizens to flock, resulting in the city being less than a quarter full (Poon, 2018).Among the many US cities that adopt develop smart mobility solutions, Boston started in 2016, to testing self-driving cars (with an emergency driver) in a small section of the city, with the support of a Cambridge-based startup called nuTonomy Inc (Agbali, Trillo, Fernando & Arayici 2017).

Smart urban mobility is one of the five enablers for allowing Singapore to transform and materialize its Smart Nation vision. An ITS has been under development for more than 10 years and provides a wide series of smart mobility services such as one motoring that provides traffic information, estimations of the travel time, road maps, street directions, and many more. Similarly, the analysis of data collected from sensors spread around the road network allows to track bus fleets and monitor traffic, early detect problematic areas, and seek solutions (Calder, 2016).

### 21.4.3 The effects

The development of smart mobility services has been based on the technological advancements that brought smartphones to everyone's hands, allowed route planning in almost real-time planning, opened traffic data, and for the first time empowered travelers with personalized information and advanced services and cities with an abundance of data, information, and valuable analytics. Augmented reality dashboards in vehicles, self-driving cars, cars that communicate with each other, vehicle sharing are some of the changes that allow us to talk for new mobility as a service landscape where:

- Public and private companies collaborate to provide integrated mobility solutions, with the private sector being the trigger for advances and the public sector guaranteeing safety and citizens' protection.
- Monitoring of road and vehicle's condition increases passenger safety and in the case of self-driving cars or AI-assisted vehicles provides comfort and safety to the driver. This is also expected to impact the car insurance industry, which is currently developing new contract types.
- Mobility services have become traveler centered and personal. Users' choices are a priority and everything grows around them. The mobility in smart cities is rich in data, allowing them to easily locate and reach stores, restaurants, parking lots and points of interest. It provides safe walks and bike-friendly rides and promises reduced driving and congestion.
- Transport networks are more integrated than ever and more intelligent than before. They can predict demand, monitor traffic, measure the network performance, and respond to emergencies. They can adjust capacity and avoid disruption.
- E-tickets and contactless payments minimize delays in queues and allow travels that combine more than one means of transportation, including personalized transportation services or own/shared cars.

## 21.5 Conclusions

The digitization of transportation has transformed the way we move within smart cities. More and more citizens are embracing new mobility options and apps that allow them to plan their journeys in real time, compare, and combine different transportation options for moving in the city or across cities. Connected vehicles, traffic lights, highways, and toll-booths have increased the security of transportation and have attracted big technology companies that collaborate with smart cities to promote efficient mobility plans for citizens. The benefits from the investment of smart cities to mobility and transportation are substantial and long term: reduced traffic brings lower logistics' costs and increased productivity, a smart combination of personalized and mass transportation is expected to reduce carbon emissions and promote a more sustainable environmental solution, whereas the successful paradigms of smart cities are expected to multiply the effect and attract more cities.

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Chapter 22

# Intelligent transportation systems and blockchain technology

## 22.1 Blockchain technology basics and applications

The internet has revolutionized the way people perceive the world and has become an integral part of their everyday life. The technologies on which it is based are evolving rapidly and new technologies always emerge. One of the most stable features of the internet, the client-server architecture on which the majority of web applications and services are still-based, seems to change greatly thanks to the new trends. Emerging technologies, including the blockchain, and the Internet of Things seem able to give to the internet a more decentralized nature.

The main concept behind blockchain technology was to guarantee that publicly shared information could be securely stored in a distributed manner. It has been designed to be a digitally distributed public ledger that records transactions and agreements in a seamless manner and is backed by a peer-to-peer network. Blockchain was originally developed for the operation of Bitcoin cryptocurrency, but is constantly evolving and now its scope has become much wider. In addition to a means of cryptocurrency operation, blockchain can be a pillar for developing and deploying decentralized applications (DApps) on distributed peer-to-peer networks instead of using an organization's servers.

Blockchain technology assumes that a network of people can create and share information in common without a centralized authority, using only a network of peers. The network is decentralized and distributed equally, which means that there is no node/person that is superior or has higher priority (of any kind) than others. All nodes of the blockchain network create and share a file together and their objective is to create and preserve this file using a set of rules that is called the consensus protocol and is used to establish trust between the collaborating persons. The file is, in essence, a distributed dataset, grouped in time-numbered "blocks" that cannot be modified. When a node wants to update the file, this is done by adding the desired update to the distributed dataset as a new block in the chain of blocks.

Blockchain is a very effective solution to the problem of trust that people face in their web transactions. Blockchain technology enables to trust the network,

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without trusting any of its participants and this is achieved using several consensus mechanisms among its peers (Zheng, Xie, Dai, Chen, & Wang, 2018). The main concept behind the consensus mechanism is to avoid an individual to control more than 50% of the peers of the network, since this can be a risk for the network itself (Nakamoto, 2008). In order to achieve this, they employ a "prove trust and get reward" strategy, according to which one or more network peers bid (invest resources) in order to add a new block in the chain and get reward for this. The nodes that maintain the network, those who create the blocks, are called miners. The process is repeated every time a new block is added to the blockchain. The peers of the blockchain network keep trusted copies of the transactions, and thus allow transactions to take place without the presence of a trusted intermediary. The blockchain itself is recording the set of transactions that have been made in the network.

The Proof of Work (PoW) and Proof of Stake (PoS) are the most popular blockchain consensus mechanisms used so far, whereas more mechanisms such as Delegated Proof of Stake (DPoS) and Federated Byzantine Agreement (FBA) are gaining space. According the PoW mechanism, the peers prove that they are trusted by contributing processing power. This is done by solving a difficult puzzle, which can be easily verified that it has been solved. When the puzzle is solved, they can validate and add the new block to the blockchain and get a reward for this, which are newly created coins. In the case of PoS, the peers that have the most stakes (coins) in the system are more likely to be chosen to be the next block validators and consequently to receive a reward. In this case no new coins are created.

The blockchain technology can be applied to a multitude of additional areas of human activity (Elsden et al, 2018; Zheng et al., 2018), such as e-government (Ølnes & Jansen, 2017), education (Chen, Xu, Lu, & Chen, 2018), health (Sharma, Hung, Agarwal, & Kalra, 2018; Mettler, 2016), the preservation and transparency of historical, financial, and other records (Lemieux, 2016), certification and traceability of products and services (Lu & Xu, 2017; Subramanian, 2018), banking, insurance, construction (Peters & Panayi, 2016; Tapscott & Tapscott, 2017), etc. In this extent, blockchain has the potential to revolutionize the centralized intelligent transportation systems (ITS) by establishing a decentralized environment that provides security and trust and allows autonomous ITS to thrive, to take advantage of legacy infrastructure and resources, and effectively utilize crowdsourcing (Yuan & Wang, 2016).

## 22.2 Ethereum blockchain and smart contracts

The Ethereum project was a milestone in the short history of the blockchain technology, because it opened the ground for developing new solutions though the implementation and execution of smart contracts. The Ethereum blockchain was not only a ledger serving financial transactions but a distributed computing architecture for the deployment of decentralized applications, which can be managed and operated through smart contracts. Smart contracts provide this flexibility through the customization of the platform in which securely decentralized applications can be created and operated. In Ethereum blockchain each node on the network records the same transactions, organizes them into blocks and adds them to the blockchain. Only one block can be added at a time and each block contains the PoW. For reducing power consumption the transition from PoW to PoS is being discussed. All code is executed in the Ethereum Virtual Machine ("EVM"), which is the center of Ethereum. Each node "runs" EVM and executes the same commands. Because of this, Ethereum is often referred to as a "global computer," in which the peer-to-peer network protocol of Ethereum is responsible for the coordination of the connected nodes and the smooth operation of the network.

The basic unit in Ethereum is the account, unlike the Bitcoin blockchain where the base unit is the transaction. The Ethereum blockchain monitors the status of accounts at each time and records all value and information transfers between accounts. Accounts can be either externally-owned, which are controlled by people that own the respective private keys, or contract accounts. In the latter case, the contract code that can be activated only by an externally-owned account (EOA), is used to control the account.

The decentralized applications (Dapps), run over Ethereum using tools and protocols that guarantee their smooth operation and avoids downtime, fraud, censorship, or third-party obstruction. It also supports a contract-oriented, high-level, a programming language is used to program the apps and their smart contracts (Papadodimas, Palaiokrasas, Litke, & Varvarigou, 2018) that control the application operation. The smart contract of an account is practically a program code that runs when the account receives a transaction. The applications store their contract code in the blockchain and thus it cannot be modified. The holders of an EOA are allowed to code new contracts and upload them in the blockchain. However, such extensions or changes are always audited. Users (EOA accounts) send transactions to the Ethereum network by signing transaction data with their private key. A transaction is valid only, if it is signed by the sender (by its private key). As a result, the network is certain that the sender of the transaction is the one who claims it and not a malicious user.

For each transaction, a small gas charge should be paid. This protects the network by rendering frivolous calculation commands and malicious attacks such as DDoS attacks unprofitable. The payment is made for the calculation and memory used by the transaction and is proportional to them. This charge (gas) is paid in the currency of Ethereum, the ether. The miners (i.e., the nodes that handle all the network transactions) collect the ether fees, as a reward for receiving, disseminating, validating, and executing transactions. Miners collect some transactions each time in blocks and then compete with other miners so they can enter it into the blockchain. Whenever a miner introduces a new block to the blockchain it receives the ethers corresponding to the transactions contained in the block. This amount is motivating the miners to perform this work.

The term smart contract was initially defined as "a set of promises, specified in digital form, including protocols within which the parties perform on these promises" (Szabo, 1996). Smart contracts are tamper-resistant since their code is recorded and verified on blockchain. Thus, they can be executed among anonymous trustless nodes with peer-to-peer control and coordination, and can have their own cryptocurrencies, which are transferred between nodes during transactions (Wang et al., 2019).

## 22.3 An ITS-oriented blockchain model

The cloud-based model currently used by most IoT solutions, has several constraints, with the primary being the bottleneck that a central authorization and control mechanism for the management of thousands of distributed devices creates. Blockchain technology has several characteristics that make it appropriate for developing intelligent solutions over an ecosystem of smart objects (i.e. sensors, processors, and actuators) (Zheng et al., 2018) and thus makes it ideal for the new generation of intelligent transportation systems. Such solutions must allow devices to prove their origin and register anonymously, without requiring a central authority to provide authentication and at the same time must guarantee transparency and auditability. With data residing on the cloud but blockchain being the intermediary network that validates all transactions, this can be feasible.

*Decentralization* is a key blockchain feature, which allows any transaction in the network to be performed directly by the peers without a central the authentication agency. This is crucial in transportation systems, where distributed management and control is necessary for avoiding performance bottlenecks and guaranteeing continuous operation of world-wide networks. The *Persistency* of transactions, which is guaranteed by their spreading across the network nodes, makes them nearly impossible to tamper and allows the easier detection of falsification attempts. This is important especially in ITS that support logistics applications (Casado-Vara, González-Briones, Prieto, & Corchado, 2018), but also in any transportation system, where user/vehicle transactions must be verified at any time. This is coined with the *auditability* of transactions, which are validated and time-stamped, and thus easily verifiable and traceable. All the data required for tracing blockchain transactions are always in the blockchain, in order to increase the overall transparency. Finally, since transportation systems strongly involve humans and human property, it is important to guarantee *anonymity* when needed. Blockchain networks, allow users to interact using one or more generated addresses in order to avoid identity exposure. This is an effort to address the concerns that have been raised for the transactional privacy of blockchain (Kosba, Miller, Shi, Wen, & Papamanthou, 2016), mainly because part of the information is publicly visible. The absence of a central authority that keeps private information definitely avoids the "single point of failure" trap but still a certain amount of transaction information is still included in the blockchain. The use of multiple addresses for the same user, partially prevents identity exposure, which is harder to occur and requires the combined use of data from multiple transactions, which are dispersed over the blockchain.

In the case of logistics, the combination of blockchain and smart contracts can allow multi-agent systems to speed-up logistics activities by removing intermediaries and coordinating all the logistic services (Casado-Vara et al., 2018). For example, with smart contracts it is easier to validate transactions before storing them in blockchain, and can be done by calling the smart-contract code, which is in a unique location in the blockchain (Wang et al., 2018). Transactions are processed independently by the smart contract code, using the data already contained in the transaction. In a logistics network all participants (i.e., sellers, producers, and shipping companies) have smart devices to monitor the status of their assets and report them to their collaborators. For example, the producers monitor the available stock and the current production, the sellers have sensors that monitor the stock in their warehouses, the products sold and the money stored and transportation companies monitor every product on their transport vehicles. Smart devices monitor every single asset unit (stock, money, cargo, etc.) and store information in the blockchain. They also monitor every process (e.g., buy, sell, or transport transactions) and validate it using smart contracts. The resulting valid transaction is stored in the blockchain too.

In the case of ITS and intelligent vehicles, blockchain technology can be used in the backbone for facilitating and securing data sharing among intelligent vehicles (Yuan & Wang, 2016). According to IBM, "blockchain of things" is a smart IoT solution, ideal for the physical part of a parallel transportation management system (Kong et al., 2013) and decentralized ITS that avoid the "double spending" (double-recorded transactions) problem. Multi-layer architectures on top of the communication layer allow data to be collected by the smart devices (IoT devices, mobile, intelligent vehicles, camera, GPS, etc.), encrypted, stored in the ledger, and used by every node that needs it. At the lower layers (data and network layers), the blockchain integrity is based on strong cryptography (miners solve hard-cryptographic puzzles as a PoW) for validating and attaching new-chain blocks. Thus, blockchain offers a decentralized technology, which eases the interaction of all ITS participants. Data are stored on blockchain nodes, and can be synchronized easily. The consensus mechanisms used by blockchain (e.g., PoS and distributed PoS), are not computationally demanding and can be performed by the in-vehicle lightweight devices, whereas coins can be used for establishing a reward mechanism. The top layers are contract and application layer and smart contracts can be the ideal solution for this. Blockchain can also provide increased security in ITS that connect a multitude of heterogeneous sensors and actuators, by securing the V2V communication among vehicles and the V2I communication between vehicles and the road-side units. In this distributed scenario, vehicles, and road-units exchange information, which must be encrypted and distributed locally using reliable communication keys. Blockchain can be used for establishing distributed key management solutions and allow—(1) new vehicles to be registered to the domain, (2) existing vehicles to periodically change their cryptographic identity (Bao et al., 2019), (3) adversary vehicles to be reported to the network after a malicious behavior (Lei et al., 2017). Leiding, Memarmoshrefi, & Hogrefe, (2016) have proposed the use of blockchain in vehicular ad-hoc networks (VANETs). They employed smart contracts in the Ethereum blockchain for executing two types of applications—(1) mandatory applications that regulate traffic, taxation and insurance of vehicles and (2) optional ones for handling operations that require information management (e.g., for traffic jams and weather forecasting).

When mobile applications such as Google Traffic, Waze, Uber or Lyft look as a black-box for end-users and their central operation poses several restrictions to how they can evolve, blockchain application can act as their alternatives. In the approach of Hîrtan and Dobre (2018), a distributed alternative to Google Traffic or Waze is based on blockchain. A lightweight blockchain architecture assumes that and point mobile applications provide and consume traffic data, which are validated by the "fully validating nodes" of the network. These nodes are permanently connected and play the role of miners in the blockchain network. Validating nodes and mobile application nodes in the same area form clusters, and produce and attach validated data to the ledger. This distinction between ordinary (controller) and miner vehicle nodes is employed in the Block-VN architecture (Sharma, Moon, & Park, 2017) and public-private key encryption is used to secure data privacy. Miner nodes comprise sensor, computing and data storage components that collect, process, and store data which is then shared to all members of the blockchain network. On top of this architecture, vehicle personalized smart services (e.g., refueling, shopping, etc.) and vehicle-sharing applications are described.

The ride-sharing network of La'zooz (http://www.lazooz.org/) proposes an open-source, decentralized alternative to Uber and Lyft. In La'zooz, car owners can share empty seats with other travelers and thus reduce the numbers of empty seats in public transportation and better utilize their cargo space. It also offers riding solutions, in which riders switch vehicles to reach their destinations. All the above, can be achieved by using the digital applications (La'zooz Dapp) of the network, which becomes a community managed transportation network that avoids the risks of a centralized management system, such as the price control and increase by demand, the leak of private information, etc.). The smartphones and computers that run La'zooz Dapp, are registered network nodes in the physical layer and are the miners of the blockchain. They are interconnected and communicate in the network layer without any central authority, whereas in the data layer they store all the ride-sharing information, schedules, and payments in a community ledger. The network proposes its own consensus algorithm, which is known as "proof-of-movement" and requires miners to drive and contribute their transportation data to the community. The zooz tokens are the main incentives for miners and are given to them depending on the distance they drive. The smart contracts of La'zooz execute algorithms that make decisions, for example, they measure the usage rate for a specific region and if needed they activate additional services for the region (Yuan and Wang, 2016).

What is very important in blockchain-enabled ITS is the smart management of the content of services, which can be controlled with smart contracts, the privacy and security of sensitive assets and the tolerance to unpredicted failures (e.g., sensor breakdowns, etc.).

## 22.4 Conclusions

Blockchain is a rising technology that promises decentralized control of data and transactions shared among individuals and as such can be a foundation technology for IoT data sharing in the context of ITS. The progress in smart contracts and related technologies allow interested parties to create distributed and decentralized solutions that respect the privacy and security of sensitive data. The successful paradigms of other sectors that have already adopted blockchain, can be transferred to transportation using a multi-layer architecture that builds on data encryption and data sharing and usage under smart contracts.

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Chapter 23

# Conclusions and way forward

## 23.1 The future of ITS

This book aims at constituting a handbook for the latest advances on intelligent transport system (ITS), seeing them upon a set of versatile and yet complementary viewpoints. As such, it discusses on technology enablers, users, business models, regulation, policies, and standards, as well as current and emerging applications related to ITS. The growth of ITS as a concept requires a holistic and thorough investigation of all relevant aspects.

ITS are systems for implementing information and communication technologies in transport. ITS applications and services cover a wide range of areas such as: travel planners, travel information services, intelligent message boards and traffic lights, security applications (emergency automatic dialing, advanced route control system), and traffic management. Today's vehicles are already connected in many ways. However, in the near future they will also interact with each other, with road infrastructures and possibly other devices and be integrated into an ecosystem of collaborative, connected, and automated mobility. This interaction is the domain of collaborative intelligent transport systems (C-ITS).

Collaborative ITS will enable road users and traffic managers to exchange and use information and coordinate their actions. This element of synergy—made possible by digital connectivity—is expected to significantly improve road safety, traffic efficiency, and driving comfort, as it will help the driver (and future automated vehicles) make the right decisions and be adapted to the traffic situation. Their development is aimed at achieving results in reducing energy consumption and reducing environmental impacts. As they combine information and communication technologies, they can lead to more efficient, safer, and more economical traffic for people, vehicles, or goods. This combination of telematics, IT, and telecommunications enables real-time information exchange and is applicable to all transport sectors. Multimodality in travel comes through the use of various modes of transport, with the aim of optimally exploiting infrastructure, helping to resolve congestion and leading to more environmentally friendly means. These systems allow the exchange of data using wireless technologies between vehicles and the road infrastructure with the aim of increasing road safety. A key prerequisite is the proper installation of equipment at key points and the development of "intelligent" mobile applications.

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Electric vehicles constitute a challenge with the location of vehicle charging stations, their connection to "smart" energy grids, the improvement of the range of one-way traffic, as well as the charging technologies. Another problem, already facing advanced markets, is the way in which electric car charging stations affect the power grid as sudden charging causes an imbalance in the grid. It is therefore essential to integrate the infrastructure networks as well as the networks to communicate with each other through a centralized platform. Automated driving aims to increase both road safety and traffic flow through the use of automated vehicles. However, the appropriate legislative framework is needed, as well as modifications to transport infrastructure, such as the exclusive use of lanes for motor vehicles. It is a technological "revolution" that has already improved, and continues to improve, the lives of citizens. It promises a breakthrough in urban traffic management centers through the collection and processing of data for optimal management of transport infrastructures and early accident response. However, new techniques are needed for real-time traffic forecasting, as well as the installation of equipment at focal points.

Increasing energy efficiency is a prime goal with a particularly important parameter being energy production and consumption and their impact on the natural environment. ITS can help reduce emissions from transport, namely $CO_2$ and other gases that pollute the atmosphere, giving weight to traffic congestion, reducing travel time and increasing traffic safety. Although it has been internationally recognized that there is no consistent methodology that allows scientists to estimate the potential $CO_2$ emissions that the use of ITS technologies could reduce, their value will also be judged by their ability to contribute to transports cause less carbon emissions, less fuel, mainly due to congestion reduction. Improved safety can be achieved, and therefore indirectly reduced emissions, to avoid congestion that could cause accidents.

## 23.2 The upcoming trends

ITS are emerging, year after year, as one of the major segments of the world market for products and services and their widespread use can make a decisive contribution to the development and optimal exploitation of competitive advantages. Moreover, in the (not so far) future, the following trends are (among others, of course) expected to prevail:

- The countries will increasingly choose ITSs applications, as the most efficient way to optimize their investments in infrastructure.
- Vehicle-to-vehicle safety systems will attract the interest of many countries and automakers, but their commercial development will remain long lasting.
- The development of cities will keep pace with integrating ITSs applications into transport plans and systems, which will lead to ambitious and integrated management systems of transport.

- The companies will promote universal and extensive transport solutions, but their adoption will be slow and gradual.
- Continuously innovative smart systems will begin to show up, but with a slower adoption from mainstream applications.
- Ambitious applications, such as autonomous vehicles, will remain difficult to reach goals, "mainly due to political and personal objections and not because of lack of know-how."
- Growth will continue and intensify third-party apps for mobile devices.
- Cities will deal with issues of conventional (legacy) infrastructure and issues compatibility.
- Strong political leadership will be required for the ambitious administration of the new era of coming applications related to transport

It is our responsibility to incorporate the social dimension into the planning and policies for the future of urban transport and travel, to ensure that the most vulnerable social groups and the poorest economic citizens are not excluded in their movements—an integral part of their daily lives. Transport and travel should remain affordable to all citizens and facilitate the mobility of people with disabilities. ITS are undoubtfully a fundamental prerequisite toward this direction and toward improving the quality of human life as a whole.

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## S

# THE FUTURE OF INTELLIGENT TRANSPORT SYSTEMS

Intelligent Transport Systems (ITS) are developing rapidly and have the potential to transform all aspects of transportation in the near-future. ***The Future of Intelligent Transport Systems*** presents key components of next generation ITS, taking a holistic approach to the most recent technological advances, and addressing the whole spectrum of future mobility.

This book considers ITS from three perspectives: users, business models, and regulation/policy. It addresses in-vehicle applications such as autonomous driving, and vehicle-to-vehicle/vehicle-to-infrastructure communication and related applications, such as personalized mobility. This book also examines ITS technology enablers such as sensing technologies, wireless communication, and computational technology; user behavior as part of the transportation chain; financial models that influence ITS; regulations, policies and standards affecting ITS; and the future of ITS applications.

***The Future of Intelligent Transport Systems*** is a comprehensive solution for up-to-date knowledge on ITS and their growing global importance.

**Key features**

- Systematically presents the whole spectrum of next generation ITS technologies
- Integrates coverage of personalized mobility and digital assistants, big data analytics, and autonomous driving
- Chapters conclude with an open-ended question to trigger thinking on technological managerial and regulatory aspects of ITS

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