OPPORTUNITIES AND BOUNDARIES OF TRANSPORT NETWORK TELEMATICS

DELIVERABLE D.T1.3.2

The opportunities of networked telematics ("Internet of things") for an improval of public transport's quality and its boundaries

Working Paper

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1. Scope and structure of the document

This work paper on "Opportunities and boundaries of transport network telematics" (deliverable D.T1.3.2) aims at analysing the opportunities of networked telematics ("Internet of things" IoT) for the improvement of public transport's quality and at pointing out the boundaries of these systems applied in the field of public transport in rural areas.

The document has been developed under INTERREG Central Europe project "RUMOBIL" and is one of the deliverables of the Activity 3 "Elaboration of RUMOBIL Strategy". It serves as an input to the definition of the strategy that will be adopted for the development of sustainable public transport in the rural areas specifically involved.

Within Activity 3, other two work papers give useful recommendations for the project scope, such as "Macro-economic effects of public transport for rural regions", which concerns the effects of public transport in rural areas, including the impacts on commuting, the availability of skilled labour, companies' location decision and resulting economic impacts, and "New demand patterns for public transport due to demographic change", focused on how demographic changes (aging population especially in addressed rural areas) lead to new patterns in the demand of public transport services is analysed.

In more general terms, the three reports could be transferred as well to other external European contexts in order to tackle rural mobility issues.

Being the RUMOBIL approach aimed at the promotion of sustainable mobility ("smart mobility") in rural and peripheral areas, the project activities are addressed to the definition of a Strategy, through the deliverable T1.2.2 "RUMOBIL Strategy Outline" which allows other regions' transport actors to clarify their expectations.

As schematised in the figure 1 below, the Strategy Outline includes the mobility needs in rural and peripheral areas, collected and analysed starting from information and studies, technical visits, best practices analysis, etc., and the solutions that could be applied in order to resolve or reduce the critical points. The solutions, in particular, were underlined by each project partner in order to address the problems analysed and the mobility needs to be satisfied. They can be classified in five main groups, such as:

- ✓ transport network integration and coordination, in terms of service planning (e.g. harmonised timetable, intermodal nodes) and stakeholders' involvement;
- ✓ tariff system, promoting a unified approach for each urban context;
- ✓ new specific services for rural areas, focusing on DRT-demand responsive transport services;
- ✓ infomobility, enhancing the information flow for users, also using apps and web based tools;
- ✓ social cohesion, also developing collateral projects, for example by aiming at the promotion of rural areas in the fields of social and cultural heritage.

Several different solutions have been highlighted, starting from new on-demand bus services and promotion campaigns to novel user facilitation services and more performing infomobility systems.

To be managed and improved, this actions and solutions need to get and process information. Therefore, data and information have to be collected, analysed and grouped for the subsequent steps. Thanks to the smart technologies related to the Internet of Things, information collection and analysis are easier and more effective, because these operational steps are accomplished directly by the "things" and devices included in the information flow network. In this light, the main problem is how to effectively manage and leverage large amounts of data, problem which can be dealt with through big data analytics.

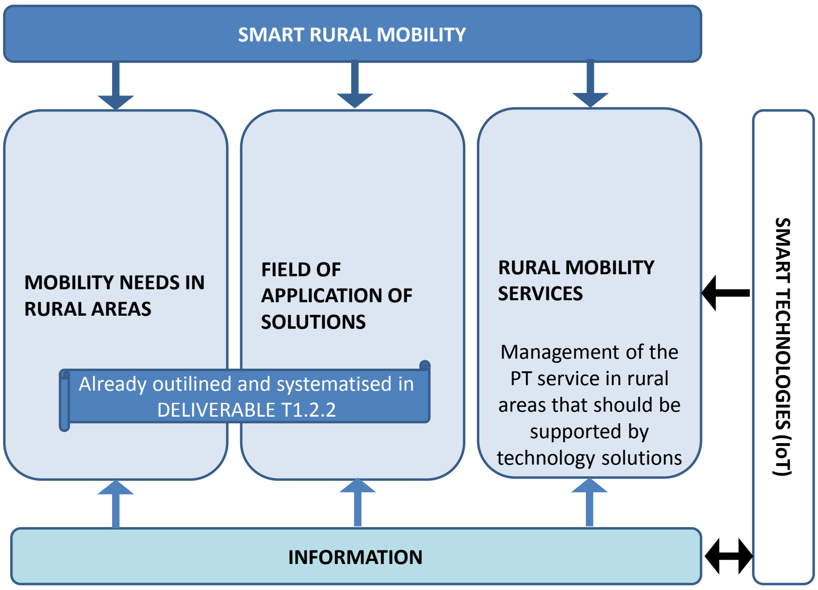


Figure 1 - A reference scheme

In closing, the management of the services and the actions to improve the smart mobility in rural areas should be supported by technological solutions, such as the Internet of Things applications. In this light, this document aims to provide an overview of the current state of the art of this field, focusing on concrete solutions that can be considered in each specific mobility sector.

The document is structured as follows:

- ✓ Chapter 2 – INTRODUCTION TO IOT contextualizes the evolution of the Internet services that lead to development of the general concept of Internet of Things;
- ✓ Chapter 3 – RESEARCH METHODOLOGY describes the approach followed in the development of the survey
- ✓ Chapter 4 – IOT TECHNOLOGIES presents a general review of the main technologies, devices and techniques enabling the implementation of the IoT paradigm
- ✓ Chapter 5 – IOT APPLICATIONS illustrates the main fields of application of IoT solutions
- ✓ Chapter 6 – IOT AND TRANSPORTATION focuses on the opportunities enabled by the implementation of IoT solutions in the specific field of Transport and Mobility, leading to the new concept of Smart Transport.
- ✓ Chapter 7 – IOT APPLICATIONS ON MOBILITY discusses the state of the art of smart transport frameworks, by presenting a series of projects in which such principles have been realized and demonstrated, through the implementation of IoT solutions
- ✓ Chapter 8 - OPPORTUNITIES outlines the most promising processes and activities concerning mobility management, which are expected to be disrupted by innovative IoT applications; the different expected impact on urban and rural mobility are compared;
- ✓ Chapter 9 – CHALLENGES warns against the limitations and problems arising within the new scenarios resulting from the adoption of such technologies in urban and rural context, and that shall be considered and tackled in order to be able to maximise benefits;
- ✓ Chapter 10 - UE REGULATORY FRAMEWORK reviews the main regulations and planning documents concerning the issues of innovation of the Community Transport System and the technological aspects of mobility.

2. Introduction of Internet of Things

Starting as a static repository of interlinked hypertext documents, over the past decades, the Internet gradually changed into a dynamic universe of networked humans, machines and applications. As shown in Figure 2, the internet went through different phases [1]:

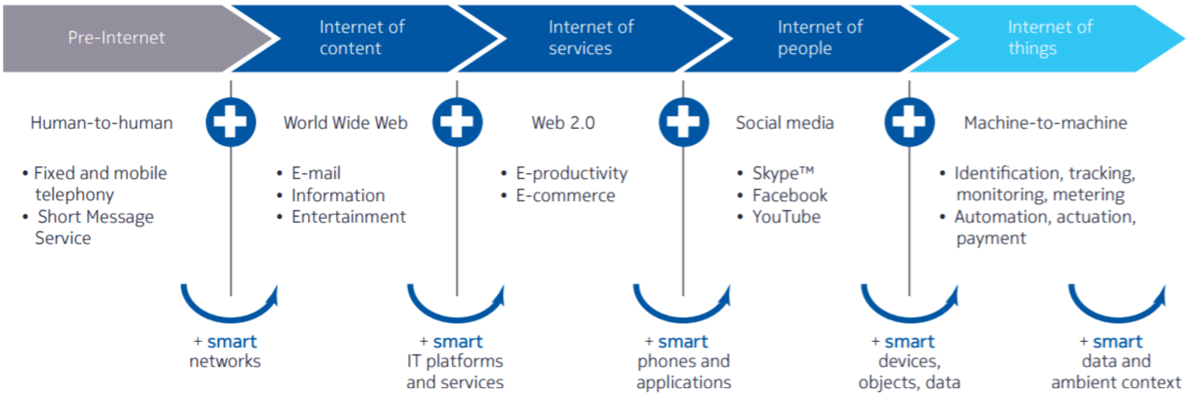


Figure 2 - The evolution of the Internet [1]

The Internet of content. The definition of the HTTP protocol and the creation of the World Wide Web (WWW) marked the creation of the the "real" internet, that is, the Internet we all use today. In this phase, the Internet was static and used for publishing and sharing content.

The Internet of services. During this phase, XML, web services, user-generated content, productivity and collaboration tools, together with the advent of the e-commerce, brought the Internet far from the static pages of the early websites and eventually led to the Web 2.0.

The Internet of people. The wide adoption of mobile devices with broadband access and the increasing popularity of social network apps brought about the current phase of the Internet evolution, which we are leaving in favour of the Internet of things.

The Internet of things. The increasing use of Machine-to-machine (M2M) communications and big data analytics is bringing about another revolution in the way we are using the Internet. In this phase, objects are becoming part of information systems and end-user applications, effectively creating a ubiquitous and unlimited universe where machines and humans interact to make our society safer, greener and healthier. Based on the 2014 and 2015 editions of Gartner's Hype Cycle for Emerging Technologies, the Internet of Things is at the top of the cycle and will reach full maturity in 5 to 10 years.

The next wave in the era of computing will be outside the realm of the traditional desktop. In the Internet of Things (IoT) paradigm, many of the objects that surround us will be on the network in one form or another. Radio Frequency IDentification (RFID) and sensor network technologies will rise to meet this new challenge, in which information and communication systems are invisibly embedded in the environment around us. This results in the generation of enormous amounts of data which have to be stored, processed and presented in a seamless, efficient, and easily interpretable form. This model will consist of services that are commodities and delivered in a manner similar to traditional commodities [2]. Cloud computing can provide the virtual infrastructure for such utility computing which integrates monitoring devices, storage devices, analytics tools, visualization platforms and client delivery. The cost based model that Cloud computing offers will enable end-to-end service provisioning for businesses and users to access applications on demand from anywhere.

Smart connectivity with existing networks and context-aware computation using network resources is an indispensable part of IoT. With the growing presence of WiFi and 4G-LTE wireless Internet access, the evolution towards ubiquitous information and communication networks is already evident. However, for the Internet of Things vision to successfully emerge, the computing paradigm will need to go beyond traditional mobile computing scenarios that use smartphones and portables, and evolve into connecting everyday existing objects and embedding intelligence into our environment. For technology to disappear from the consciousness of the user, the Internet of Things demands: (1) a shared understanding of the situation of its users and their appliances, (2) software architectures and pervasive communication networks to process and convey the contextual information to where it is relevant, and (3) the analytics tools in the Internet of Things that aim for autonomous and smart behavior. With these three fundamental grounds in place, smart connectivity and context-aware computation can be accomplished [3].

The term Internet of Things was first coined by Kevin Ashton in 1999 in the context of supply chain management [4]. However, in the past decade, the definition has been more inclusive covering wide range of applications like healthcare, utilities, transport, etc. [5]. Although the definition of 'Things' has changed as technology evolved, the main goal of making a computer sense information without the aid of human intervention remains the same. A radical evolution of the current Internet into a Network of interconnected objects that not only harvests information from the environment (sensing) and interacts with the physical world (actuation/ command/control), but also uses existing Internet standards to provide services for information transfer, analytics, applications, and communications.

Fueled by the prevalence of devices enabled by open wireless technology such as Bluetooth, radio frequency identification (RFID), Wi-Fi, and telephonic data services as well as embedded sensor and actuator nodes, IoT has stepped out of its infancy and is on the verge of transforming the current static Internet into a fully integrated Future Internet [6].

The Internet revolution led to the interconnection between people at an unprecedented scale and pace. The next revolution will be the interconnection between objects to create a smart environment. Only in 2011 did the number of interconnected devices on the planet overtake the actual number of people. Currently there are 9 billion interconnected devices and it is expected to reach 24 billion devices by 2020. According to the GSMA (www.gsma.com), this amounts to $1.3 trillion revenue opportunities for mobile network operators alone spanning vertical segments such as health, automotive, utilities and consumer electronics.

The advancements and convergence of micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics has resulted in the development of miniature devices having the ability to sense, compute, and communicate wirelessly in short distances. These miniature devices called nodes interconnect to form a wireless sensor networks (WSN) and find wide ranging applications in environmental monitoring, infrastructure monitoring, traffic monitoring, retail, etc. [7]. This has the ability to provide a ubiquitous sensing capability which is critical in realizing the overall vision of ubicomp as outlined by Weiser [8]. For the realization of a complete IoT vision, efficient, secure, scalable and market oriented computing and storage resourcing is essential.

Cloud computing [9] is the most recent paradigm to emerge which promises reliable services delivered through next generation data centers that are based on virtualized storage technologies. This platform acts as a receiver of data from the ubiquitous sensors; as a computer to analyze and interpret the data; as well as providing the user with easy to understand web based visualization. The ubiquitous sensing and processing works in the background, hidden from the user. This novel integrated Sensor-Actuator-Internet framework shall form the core technology around which a smart environment will be shaped: information generated will be shared across diverse platforms and applications, to develop a common operating picture (COP) of an environment, where control of certain unrestricted 'Things' is made possible.

As identified by Atzori et al. [10], Internet of Things can be realized in three paradigms-internet-oriented (middleware), things oriented (sensors) and semantic-oriented (knowledge). Although this type of delineation is required due to the interdisciplinary nature of the subject, the usefulness of IoT can be unleashed only in an application domain where the three paradigms intersect. The RFID group defines the Internet of Things as the worldwide network of interconnected objects uniquely addressable based on standard communication protocols. According to Cluster of European research projects on the Internet of Things [11], 'Things' are active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information sensed about the environment, while reacting autonomously to the real/physical world events and influencing it by running processes that trigger actions and create services with or without direct human intervention. According to Forrester [12], a smart environment uses information and communications technologies to make the critical infrastructure components and services of a city's administration, education, healthcare, public safety, real estate, transportation and utilities more aware, interactive and efficient.

The definition of the Internet of Things for smart environments is the interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework.

3. Research methodology

In order to achieve the aim of analysing the opportunities of the Internet of Things for the improvement of public transport's quality and of defining innovative applications in the field of public transport in rural areas, we employed a research methodology which includes:

- ✓ publication research:
    - Google Scholar
    - Companies' reports (e.g. Verizon IoT report)
- ✓ ongoing and closed IoT projects research:
    - projects related publications
    - projects websites

The study's purpose is to report information about the IoT state of the art, focusing on innovative applications of the IoT technologies on transportation and, in particular, on peripheral areas. State-of-the-art tools and solutions reported in this document are intended to support the implementation of pilot actions and the RUMOBIL strategy, as well as provide the information to predict how demand for public transport will develop in coming years.

4. IoT Technologies

Different technologies have been applied to address the specific features of each IoT application. The required technologies cover a wide range and layer from the physical level to the data and application layers.
The IoT archetype is in the power of smart and self-configuring devices which are well linked together by global grid infrastructures. IoT can be typically defined as a real object, largely dispersed, with low storage and processing capabilities, which aims at enhancing reliability, performance and security of a smart environment as well as its infrastructure. In this chapter, we present an overview of the IoT technology stack [13].

4.1. IoT layers

As shown in Figure 1, the IoT consists of three layers: the perception layer, the network layer, and the application layer. All the devices capable of perceive, detect objects, gather information, and exchange information with other devices through the Internet communication networks constitute the perception layer. RFID, cameras, sensors, Global Positioning Systems (GPS) are included in this layer.

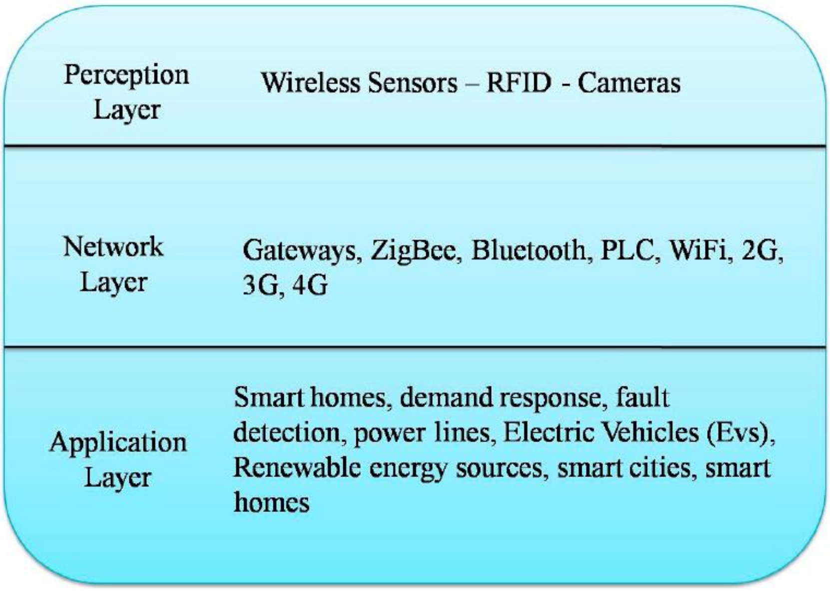


Figure 3 - IoT layers

The network layer is in charge of forwarding data from the perception layer to the application layer under the constraints of devices' capabilities, network limitation and the applications' constraints. A combination of short-range communication technologies, such as Bluetooth and ZigBee, are used to carry the information from perception devices to a nearby gateway based on the involved devices capabilities [14]. Depending on the application, information must be carried over long distances through Internet technologies such as WiFi, 2G, 3G, 4G, and Power Line Communication (PLC). Finally, the application layer is where the information is received and processed, and where smart homes, smart cities, intelligent transportation systems are effectively created.

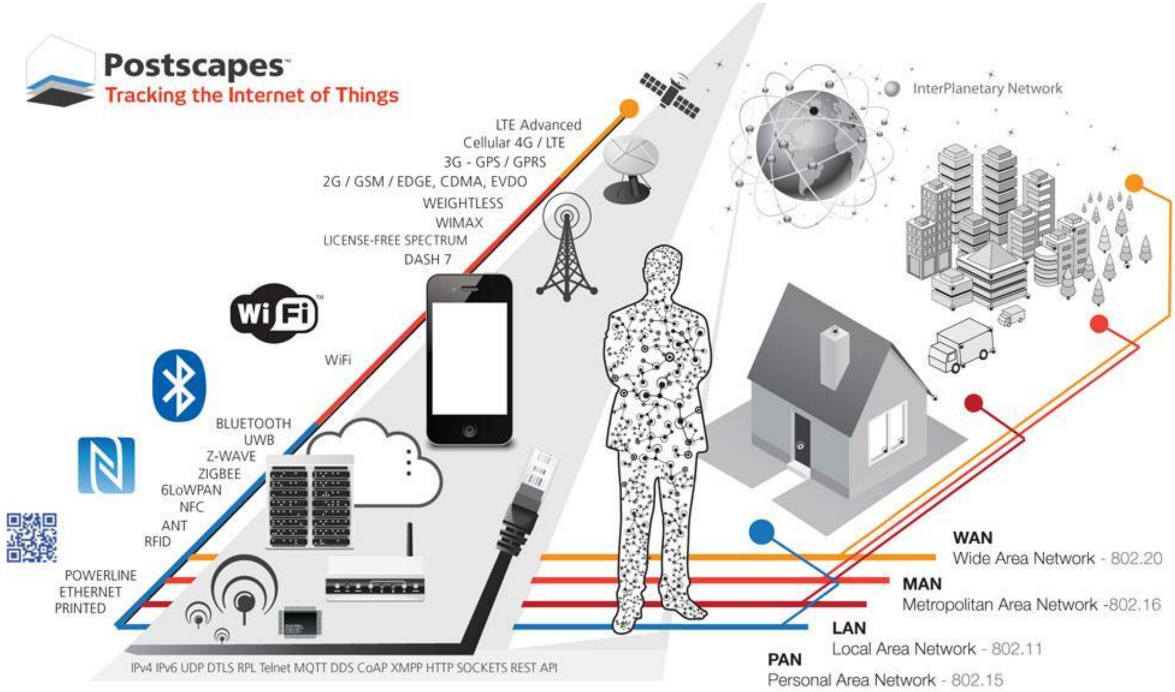


Figure 4 - A bird's eye on IoT Technologies (from www.postscapes.com)

4.2. Radio Frequency Identification (RFID)

RFID is a short range communication technology used for tracking and identifying objects wirelessly. With RFID, an RFID tag communicates with an RFID reader via radio-frequency electromagnetic fields. The readers usually send collected data to a computer system running RFID software or RFID middleware [15]. The most commonly used RFID data form in the IoT context is the Electronic Product Code, or EPC. An EPC is a universally unique identifier for an object. These unique identifiers ensure that objects tracked with RFID tags have individual identities in the IoT.

RFID is a technology which have proven to be extremely useful in tracking objects. It was not designed specifically for the IoT. The technology is widely used in logistics and supply chain management, aviation, food safety, retailing, public utilities and others. Organizations such as Wal-Mart, the U.S. Department of Defense have mandated the use of RFID. Nevertheless, RFID tracking capabilities are considered to be a precursor to the Internet of Things and RFID benefits can be extended by remotely access the data RFID provide through the Internet [16].

Relevant technical details and examples:

- ✓ Frequency: 120–150 kHz (LF), 13.56 MHz (HF), 433 MHz (UHF), 865-868 MHz (Europe) 902-928 MHz (North America) UHF, 2450-5800 MHz (microwave), 3.1–10 GHz (microwave)
- ✓ Range: 10cm to 200m
- ✓ Examples: Road tolls, Building Access, Inventory

4.3. NFC

A newer technology that builds on the RFID standard is Near Field Communication (NFC). NFC is a short-range communication standard which comprises a set of wireless technologies, where devices can radio communicate with one another when they are within a maximum distance of 10 cm from each other. A Unique Identification (UID) is associated with and contained by each NFC tag.

To make NFC communication possible an initiator and a target are always needed. Usually, the initiator powers a passive target with a RF field, allowing for NFC tags to take very simple form factors (e.g., tags, stickers, key fobs, cards) as they do not require batteries. As an example, NFC are often used in smart posters, which are able to transmit data to the user's smartphone through the NFC tag.

However, also NFC peer-to-peer communication is possible. When brought together, smartphones can usually use NFC technology to communicate, due to its wide adoption among these handheld devices.
Relevant technical details and examples:

- ✓ Frequency: 13.56 MHz
- ✓ Range: < 0.2 m
- ✓ Rate: from 106kbit/s to 424 kbit/s
- ✓ Examples: Smart Wallets/Cards/Posters, Action Tags, Access Control

4.4. Bluetooth

Bluetooth is a short-range wireless communication technology standard which use short-wavelength radio transmissions in the ISM band from 2400 to 2480 MHz. Bluetooth is employed by fixed and mobile devices and create highly secure personal area networks (PANs).

Relevant technical details and examples:

- ✓ Frequency: 2.4GHz
- ✓ Range: 1-100m
- ✓ Examples: Hands-free headsets, key dongles, fitness trackers, beacons

4.4.1. Beacons

Beacons are small wireless devices that continuously transmit a radio signal to communicate their position and ID. Usually, the signal is picked up by smartphones using Bluetooth Low Energy (BLE) technology. The smartphone reads the beacon's identification number (ID), calculates the distance to the beacon and, based on this data, triggers an action in a beacon compatible mobile app.
Beacons, in contrast with RFID, only require devices to have BLE capabilities, thus including most smartphones. Instead, RFID need specialized hardware to work, such as tags, readers, reader control and application software, which makes RFID a less easily accessible technology than beacons.

4.5. Sensor networks

Sensors are devices that monitor characteristics of the environment or other objects such as temperature, humidity, movement, and quantity. A wireless sensor network (WSN) is constituted by a set of sensors that are used together and interact, and can also contain gateways. Gateways forward data collected from the sensors to a server. A sensor is distinguished from an actuator as the former gathers information about the state of an environment or object, whereas an actuator perform actions which affect the environment or object (e.g., an actuator could generate radio waves, light, sound, smells). Such capabilities allow for IoT objects to communicate with people. Actuators are used in combination with sensors to build sensor-actuator networks. In a sensor-actuator network, an actuator may be used to generate an alarm to alert people to the presence of a toxic gas, action which would be triggered by a sensor detecting the presence of carbon monoxide in a closed space. In this way, sensors and actuators work together to give objects the capability to be aware of their environment and, at the same time, interact with people.

4.6. Low Rate Wireless Personal Area Network (LWPAN)

Among short-range radio technologies — which cover larged distances, up to 10-15 km - LWPAN features very low energy consumption which allow for batteries to last up to 10 years [17]. According to the IEEE 802.15.4 standard, it provides low cost and low-rate communication for sensor networks. In addition to the 6LoWPAN and ZigBee [18] upper layers protocols, LWPAN technology has also the lowest two layers of protocols including physical and medium access level.

4.6.1. ZigBee

ZigBee is a low-power, low-cost wireless communication technology used by sensor nodes [19]. Based on the IEEE 802.15.4 standard, ZigBee allows the creation of wireless personal area networks (WPAN) for use in home automation, medical device collection and other low-power, low-bandwidth applications, including wireless light switches, electrical meters, and traffic management systems. ZigBee is suitable for limited ranges, coverage of a city's region and supporting billions of devices. Moreover, a mechanism for the transmission of IPv6 packets is specified. ZigBee applications usually require additional equipment such as a coordinator, a router and ZigBee end-devices.

4.6.2. 6LoWPAN

6LoWPAN standard is specified as a compression format for IPv6 communication. IPv4, the pred ecessor of IPv6 and leading addressing technology supported by Internet hosts, has been replaced by IPv6 due to the exhaustion of the IPv4 address blocks and the inability to separately address billions of nodes which is a characteristic of IoT networks. IPv6 solves the shortage of IPv4 nodes by providing 128-bit addresses for IoT networks. However, it causes another issue, that is, compatibility with constrained nodes, which can be overcome by using 6LoWPAN standard [20].

4.7. Wireless Sensor Networks (WSN)

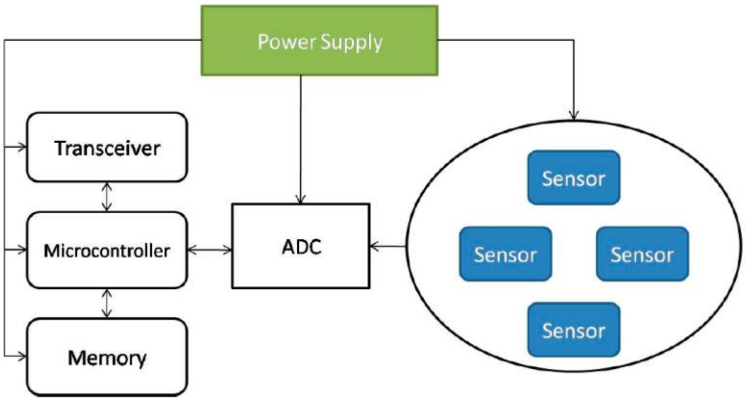


Figure 5 - The architecture of a Wireless Sensor Node

Efficient, low cost, low power miniature devices for remote sensing applications have been made available by recent technological advances in low power integrated circuits and wireless communications. The combination of these factors has increased the adoption of sensor networks containing multiple intelligent sensors, which collect, process, analyse and disseminate valuable information, gathered in a variety of environments. Lower end WSN nodes include active RFID, which have limited processing capability and storage.

The scientific challenges that must be overcome in order to realize the enormous potential of WSNs are substantial and multidisciplinary in nature. Sensor data are shared among sensor nodes and sent to a distributed or centralized system for analytics. A WSN monitoring network contains: (i) WSN hardware: the WSN core hardware (referred to as WSN node) contains sensor interfaces, processing and transceiver units, and a power supply. Multiple A/D converters are almost always necessary to interface sensors. More recent sensor nodes can communicate using one frequency band, which makes these sensors more versatile [7]; (ii) WSN communication stack: most applications require nodes to be properly deployed. A proper topology, routing and MAC layer design is critical for the scalability and longevity of the network. WSN nodes communicate and transmit data in a single or multi-hop fashion to a base station. Node drop outs are the main cause of network lifetime degradation. The communication stack at the sink node should ensure interaction with the outside world through the Internet, thus acting as a gateway to the WSN subnet and the Internet; (iii) WSN Middleware: access to heterogeneous sensors resources can be provided by WSN Middleware, a mechanism to properly combine cyber infrastructure with a Service Oriented Architecture (SOA) and sensor networks.

The idea behind this mechanism is that of isolating resources that can be used by several applications. A platform-independent middleware such as an Open Sensor Web Architecture (OSWA) makes it possible to develop sensor applications [18]. OSWA is built upon a uniform set of operations and standard data representations as defined in the SensorWebEnablement Method (SWE) by the Open Geospatial Consortium (OGC); (iv) Secure Data aggregation: to extend the network lifetime, and to ensure the reliability of sensors' data collection, an efficient and secure data aggregation method is required [18]. WSNs are prone to node failures, thus requiring the network topology to be self-healing. As the system is automatically linked to actuators, ensuring security is a critical issue, and protecting the systems from intruders becomes very important.

4.8. DASH7

Long distance and low power sensing applications (e.g., building automation, logistics) can benefit from the use of DASH7, a promising standard for WSNs. The DASH7 protocol is appealing for HANs, as it is designed for kilometer-distance range applications and operates at 433 MHz, thus ensuring better penetration through walls than 2.4 GHz. DASH7 can be effectively employed in military applications (especially substation construction), hazardous material monitoring, manufacturing, warehouse optimizations, smart meter development, and others [21].

4.9. 3G and Long Term Evolution (LTE)

3G and LTE are standards for wireless communication for mobile phones and data terminals. As far as development and expansion of wireless communication infrastructures are concerned, LTE and 3G are available everywhere, even in third world countries. Designed for broadband connectivity, these technologies are not the most appropriate for short range uses; their field of applications includes WANs, which require longer distance ranges. Among the issues that affect their implementation are the high data cost sustained by service providers, and inability to use them to allow for communication among billion devices.

4.10. IoT Analytics

Storage, ownership and expiry of the data are becoming critical issues. As the internet consumes up to 5% of the total energy generated today and it is bound to increase for years to come, centralized data centers that run on harvested energy will have to ensure energy efficiency as well as reliability. Smart monitoring and actuation requires the data to be stored and used intelligently. Advanced artificial intelligence algorithms which could be centralized or distributed according to current needs will be developed, as well as novel fusion algorithms which will make sense of the collected data. Automated decision making will be enabled by state-of-the-art, non-linear, temporal machine learning methods based on evolutionary algorithms, genetic algorithms, neural networks, and other artificial intelligence techniques. All these systems will have to feature interoperability and integration capabilities, as well as ensure adaptive communications.

More importantly, a centralized infrastructure - the IoT middleware - is required to support storage and provide analytics. Finally, cloud based storage solutions are becoming increasingly popular and, in the years ahead, Cloud based analytics and visualization platforms are foreseen. IoT analytics can be descriptive, predictive, and prescriptive analytics, which can be distinguished as follows:

- ✓ Descriptive analytics. Focus on the past via data aggregation and mining (answers: “What has happened?”).
- ✓ Predictive analytics. Focus on the future through the use of forecasting techniques and statistics (answers: “What could happen?”).
- ✓ Prescriptive analytics. Focus on advices and prescriptions, by employing optimization and simulation algorithms to advise on outcomes and machine automation (answers: “What should be done?”).

Distinguishing predictive analytics from prescriptive analytics is not straightforward. Predictive analytics may be seen as closed-loop, but, in fact, they require human intervention to determine which is the most suitable solution to a problem: people and also machines can be alerted, but predictive analytics can not figure out which is the ideal remedy by themselves. On the other hand, prescriptive analytics can weigh all the different possible actions, and eventually invoke actions, thus removing the barrier between insight and action. Prescriptive analytics need to be supported by a knowledge base and automation.

4.10.1. Machine Learning

IoT generates large amounts of data which, by 2020, will be produced at the edge or the area where the endpoints operate [22]. Storage, ownership and expiry of the data become critical issues. The ever-increasing power consumption of the Internet makes of centralized data centers effective solutions for ensuring high efficiency and reliability. Artificial intelligence algorithms must be developed with the possibility of deploying them through a centralized or distributed manner in mind.

Huge amounts of data can be managed through machine learning, which is a process that harnesses computing power to deal with the volume and velocity of incoming information flows. Machine learning provides ways to build and test several data models based on the incoming data, also changing the models as new data comes in. The data models can be also differentiated to allow for selecting the most suitable one according to specific criteria.

Automated decision making, inherent in prescriptive analytics, require state-of-the-art non-linear, temporal machine learning methods based on evolutionary algorithms, genetic algorithms, neural networks, and other artificial intelligence techniques. These systems feature interoperability, integration and adaptive communications.

5. IoT applications

The emerging Internet of Things will impact several application domains. Aspects such as network availability, coverage, scale, heterogeneity, repeatability, user involvement and impact can serve as a base to distinguish and classify IoT applications [3]. Applications can be categorized into four application domains: (1) Personal and Home; (2) Enterprise; (3) Utilities; and (4) Mobile.

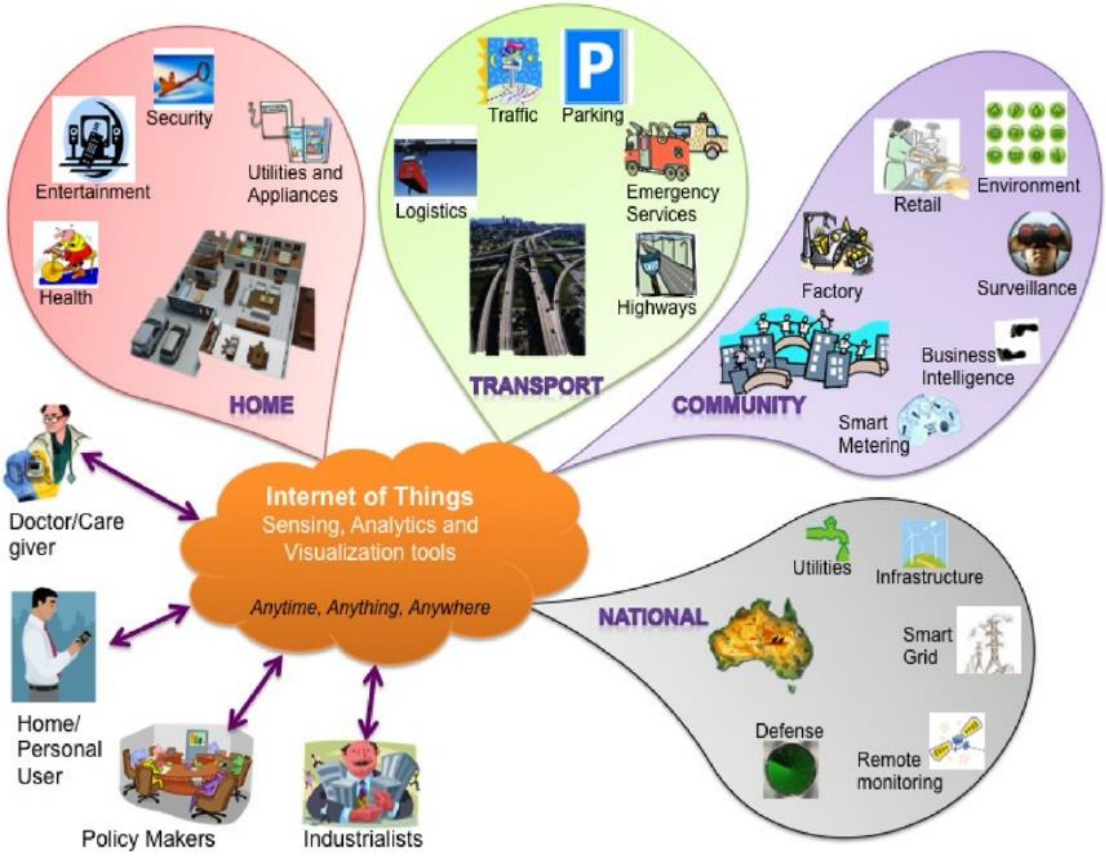


Figure 6 - IoT applications

In Figure [6] a schematic of the interconnection of objects is depicted, where the scale of the impact of the generated data determines the application domains. Users can be from individuals to organizations at the national level, and addressed issues are widely varied. Personal and Home IoT are represented at the scale of an individual or home, Enterprise IoT at the scale of a community, Utility IoT at a national or regional scale and Mobile IoT, which has a variable scale depending on the nature of the application domain and the required connectivity, is spread across several domains.

Applications and the use of data are subject to huge crossover between domains, such as that observable for, the Personal and Home IoT, which produces household electricity usage data and makes it available to the electricity provider which, in turn, can optimize supply and demand in the Utility IoT domain. Different service providers can rely on the internet for seamless data sharing, thus creating multiple business opportunities. In the following paragraphs, we provide a few typical applications in each domain.

Personal and home. In personal and home applications only the network's owners can use the information collected by the sensors. WiFi is the most commonly used backbone technology, thus ensuring higher bandwidth for transferring data and higher sampling rates for applications which rely on audio information.
Personal body area networks can be used to realize the ubiquitous healthcare vision. Indeed, physiological parameters can nowadays be measured by sensors using technologies such as Bluetooth, capable of seamlessly communicate with portable devices (e.g., smartphones). Ubiquitous healthcare can thus rely on IoT, which configures itself as an optimal platform where body area sensors collect information which can then be uploaded to servers [10]. So far, there are several applications available for Apple iOS, Google Android and Windows Phone operating systems that measure various parameters. However, general physicians still can not leverage centralized applications. An extension of the personal body area network is creating a Home monitoring systems can extend personal body area network to allow for elderly care, enabling the doctor to monitor patients in their homes thereby reducing hospitalization costs through early intervention and treatment [23, 24]. Household energy management could also benefit from IoT, through ensuring users deeper control over home equipment such as air conditioners, refrigerators, washing machines.

Enterprise. For classifying purposes, a 'Network of Things' within a work environment is here defined as an enterprise based application. In this domain, only the owners of such networks can use the collected data, which can be released selectively. An example of an application within this domain is environmental monitoring where the number of occupants is tracked and the utilities within the building are managed (e.g., HVAC, lighting). Aspects such as security, automation, climate control always require sensors to be deployed, and the relative management systems will eventually be replaced by a wireless system. This will allow for changes to be made whenever necessary.

Utilities. This application domain uses information from the networks to optimize services rather than to provide data to be directly consumed by the user. Utility companies are already using these data to manage resources with the aim of optimizing cost-profit ratio. Very extensive networks are needed for efficient resource management and monitoring critical utilities, networks which are usually deployed by large organizations on a regional and national scale). The information from the networks in this application domain is usually for service optimization rather than consumer consumption. It is already being used by utility companies (smart meter by electricity supply companies) for resource management in order to optimize cost vs. profit. These are made up of very extensive networks (usually laid out by large organization on a regional and national scale) for monitoring critical utilities and efficient resource management. The backbone network can vary between Cellular, WiFi and satellite communication.
Smart grid and smart metering is another potential IoT application [25], whose optimal energy consumption management can be achieved by continuously monitoring every electricity point within a house and using this information as a feedback to modify electricity consumption patterns.

Mobile. The nature of data and the required backbone implementation set smart transportation and smart logistics aside from other IoT application domains. Noise pollution is mainly due to urban traffic, which is also a major cause of air pollution and greenhouse emissions. In most cities, economic and social activities are significantly affected by traffic congestion and its associated costs. Just-in-time operations, as welle as others supply chain efficiencies and productivity, are severely impacted by traffic congestion causing delivery schedule failures and freight delays. Freight movement can benefit from dynamic traffic information, which allows for improved scheduling and better planning. IoT will enhance online monitoring of travel times by means of large scale WSNs, origin-destination (O-D) route choice behavior, queue lengths, and air pollutants and noise emissions. Existing sensor networks of inductive loop vehicle detectors employed at the intersections of existing traffic control systems will likely be replaced by IoT systems. Such systems will also underpin the development of scenario-based models for the planning and design of mitigation and alleviation plans, and lead to improved urban traffic control algorithms, including multi-objective control systems. Valid and relevant traffic conditions can be presented to travelers combined with information gathered from the urban traffic control system [26].

The current IoT penetration in a number of digital products such as mobile phones is testified by the wide adoption of Bluetooth-enabled (BT) devices, such as car hands-free sets and navigation systems. BT sensors can read the unique Media Access Identification (MAC-ID) number emitted by BT devices within the coverage area. The movement of devices can be detected by placing BT Readers at different locations. Other data sources such as bus GPS, or traffic signals, can complement data collected by BT devices to collect information concerning vehicle travel time on motorways and arterial streets, dynamic (time dependent) O-D matrices on the network, identification of critical intersections, and accurate and reliable real time transport network state information [27]. Such usages carry with them many privacy concerns. Digital forgetting where privacy is a concern is an emerging domain of research in IoT [28].

Efficient logistics management is another important application in mobile IoT domain [27]. In particular, monitoring transported items and transportation planning efficiency are aspect relevant to this kind of applications. Items are mainly monitored locally, for instance, within a truck replicating enterprise domain, whereas transport planning relies upon large-scale IoT networks.

In Table 1 application domains and their most relevant features are reported.

	Smart home/office	Smart retail	Smart city	Smart agriculture/forest	Smart water	Smart transportation
Network size	Small	Small	Medium	Medium/large	Large	Large
Users	Very few, family members	Few, community level	Many, policy makers, general public	Few, landowners, policy makers	Few, government	Large, general public
Energy	Rechargeable battery	Rechargeable battery	Rechargeable battery, energy harvesting	Energy harvesting	Energy harvesting	Rechargeable battery, Energy harvesting
Internet connectivity	Wifi, 3G, 4G LTE backbone	Wifi, 3G, 4G LTE backbone	Wifi, 3G, 4G LTE backbone	Wifi, satellite communication	Satellite communication, microwave links	Wifi, satellite communication
Data management	Local server	Local server	Shared server	Local server, shared server	Shared server	Shared server
IoT devices	RFID, WSN	RFID, WSN	RFID, WSN	WSN	Single sensors	RFID, WSN, single sensors
Bandwidth requirement	Small	Small	Large	Medium	Medium	Medium/large

Table 1 - Smart environment application domains

6. IoT and transportation

Smart Mobility is deeply connected to sustainable mobility, and thus leads to improving quality of life. Nowadays, huge amounts of real-time data can be processed and used to optimize the urban infrastructure, thereby making public transport services more efficient from both the final user's and the service provider's perspective. Location-based data analysis allows for identifying the most useful services for citizens at a certain time. For instance, citizens could easily navigate the most efficient routes and modes of travel.

In the report for the Sustainable Mobility Project 2.0 (SMP2.0) within the World Business Council for Sustainable Development [29], the authors described 22 indicators for parameters and methodologies to be used by cities to identify their sustainable mobility performance. Several of the identified indicators are also relevant to smart urban mobility (e.g., congestion and delays, mobility space usage, commuting travel time, access to mobility services, comfort and pleasure, traffic safety, occupancy rate and intermodal connectivity). Smart urban mobility also tries to find synergies between a range of technologies such as vehicle manufacturing, transport information systems, communications technologies and logistics.

Compared to other cities in the world, European ones boast better public transport services and are usually more committed to promote sustainability and low-carbon solutions. Among the european cities that have shown the most innovative actions in recent years are Copenhagen, Amsterdam, Vienna, Barcelona, Paris, Stockholm, London, Hamburg, Berlin, and Helsinki. However, there is still room for improvement at a European level aiming at a decrease of pollution and carbon dioxide emissions. Plans to restrict traffic and parking in downtown areas have already started in several European cities with interruption of the production of industrial plants, or via speed limitations to reduce the current high levels of carbon dioxide output. For instance, in the city of Amsterdam, citizens are being provided with technologies that ensure a better quality life in the city through the Amsterdam Smart City Project (Amsterdam smart city project, https://amsterdamsmartcity.com). The project will provide free Wi-Fi and a new optical fiber network. Additionally, emissions are being reduced via "smart grid" technologies for transportation, which guide trucks to available unloading areas, and control traffic lights and bridges, providing residents with personalized travel advice.

IoT sensors have been greatly enhanced over the last few years. Ubiquitous information access via the Internet has received considerable attention from citizens. Population is growing at a faster pace due to the high concentration of resources and facilities within the urban areas, which attracts more and more people from rural areas to cities. In addition, the current 54% of world's population that lives in urban areas is expected to increase to 66% by 2050.
The following figures correlate smart transport applications and the corresponding data on which they rely.

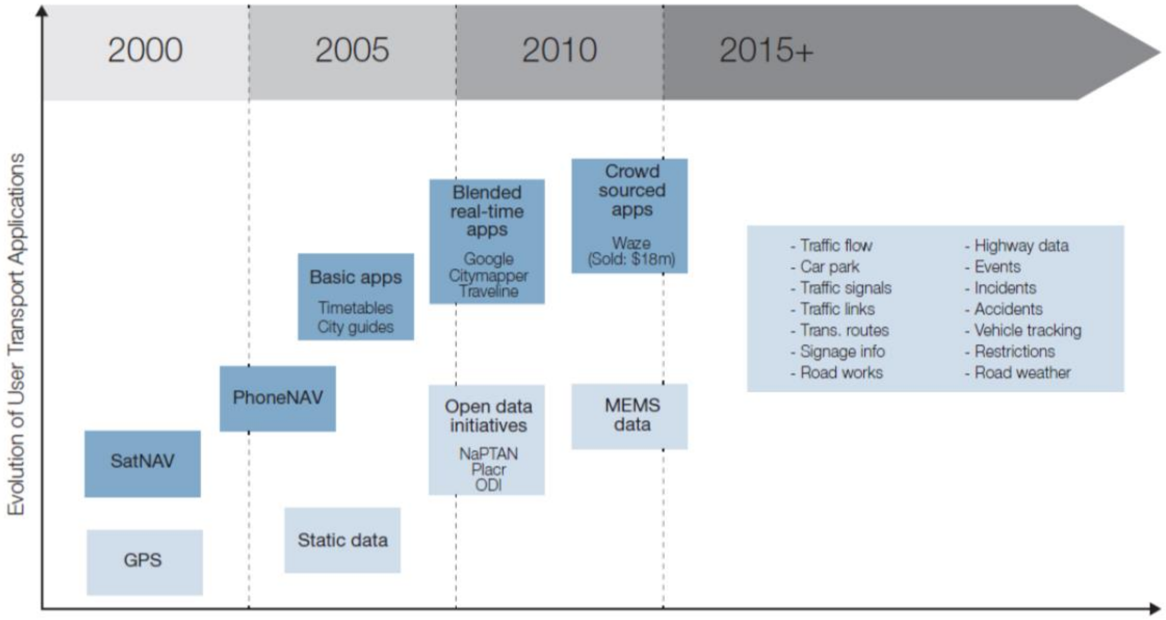


Figure 7 - The evolution of User Transport Applications and related User Transport Data Assets (from: http://www.interdigital.com)

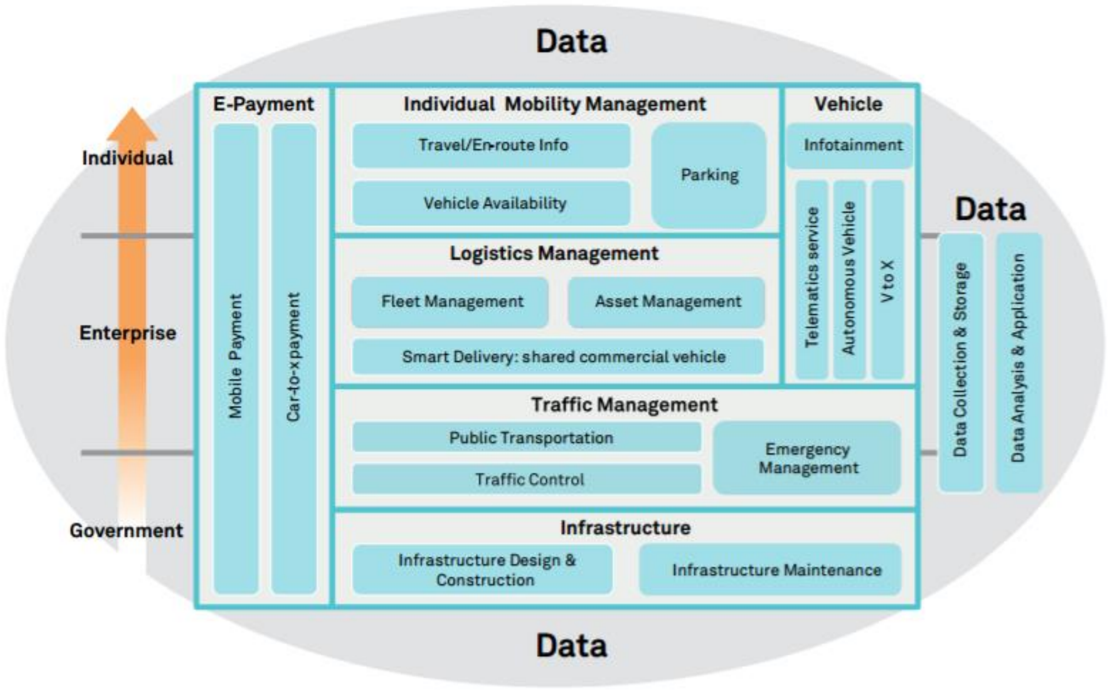


Figure 8 - Framework of Smart Transportation (from: http://www.huawei.com)

In [30] an overview of different aspects and factors which define "Smart Mobility" is provided. Efficient and effective services have been provided to citizens through multiple projects and initiatives started in recent years. Nevertheless, among other benefits, especially environmental ones can still be provided. Knowledge sharing and communication are fostered

by applied technologies, which can be also leveraged to gather feedback from citizens, and ease data acquisition for the purpose of studying mobility patterns. A fundamental goal is to reduce greenhouse gas emissions and traffic congestion, result which can be achieved through environmentally friendly, efficient, safer, and multimodal data-reliant road transport services.
To this purpose, road infrastructure can be equipped with sensors capable of recognizing and monitoring a wide range of transport-related activities. In addition to affecting the driving experience, autonomous driving will impact mobility via regulatory, social and economic changes, and will also lead to modify urban planning. Cities will be highly affected by Realistic Vehicular Ad Hoc Networks (VANETs) and the related technologies (e.g., those employed in autonomous car applications). Roads will be safer, considering that 90 percent of road accidents are caused by human error (according to the International Organization for Road Accident Prevention). In fact, fully autonomous vehicles will require no driver intervention in the control of the vehicle.

6.1. Mobility patterns

Driving behaviour can be studied through monitoring mobility patterns. A deeper knowledge on driving behaviour can improve traffic management by allowing for traffic congestion reduction and an increase in road safety. In fact, mobility patterns provide crucial information about the big picture of people's habits and routes. Personal multimodal mobility services greatly benefit from mobility pattern information, as this allow for technological applications to suggest travel routes and create new habits.

The monitoring process can be facilitated through the collection of crowd-sourcing data from mobile devices and the processing capabilities provided by cloud-based architecture, thus allowing for travel pattern changes based, for instance, on new routing recommendations. This approach gives users the possibility to use additional services. As an example, users could benefit from shorter traveling time or fuel savings obtained through simply following alternative route paths recommendations and/or feedback on their current driving patterns. Leveraging gamification approaches can also lead to changes in mobility habits, by, for instance, awarding with discounts on certain services commuting users who avoid rush hours or use public transportation. Driver behaviour can be also improved by assigning scores which educate drivers in avoiding unsafe actions. Moreover, a vehicle occupancy rate can be approximately calculated by using smartphone technology, and then used as a parameter for smart mobility.

Replacement of private vehicle use with public transportation use is enabled by leveraging urban mobile data to develop intelligent mobility concepts. This, in turn, causes traffic reduction and consequently efficient flow of the remaining vehicles, eventually lowering total carbon emissions. An optimal balance between transit use and personal vehicles would provide faster commutes and benefit the environment. To achieve this goal, urban mobility is being improved via real-time route planning. Weather, accidents, maintenance works, and public events all affect both public transportation and private vehicle use, thus requiring clear and accurate real-time information to support commuters in making decisions regarding the use of personal vehicles or public transportation services, and which mode of transportation to use to better fit their needs.

6.2. Traffic Data and Cooperative Systems

Mobile devices or cars can be used to acquire urban traffic data available on road infrastructure. For example, in [31] the authors deployed Bluetooth scanners along the freeway/arterial network in the road proximity to study and characterize urban traffic conditions. Information on travel time thus collected allowed for manage, control, and optimize traffic effectively, and provided the basis for enhancing existing routing algorithms. Logistics-related costs and environmental impact are positively affected by such IoT applications.

Road safety is certainly improved through the use of cooperative systems capable of broadcasting traffic data to enable exchange of information. Urban environments serve this purpose by providing the test bed conditions required by realistic experiments which use massive amounts of valuable data. Leveraging urban environment allows for evaluating a wide range of protocols, but also the interaction with in-vehicle systems and services. For example, within the design and development of the See-Through System [32, 33] potential connectivity issues and data transmission delays were tested by performing experiments under real conditions using the 802.11p standard wireless communication protocol.

Further cooperative approaches can improve drivers' visual awareness (e.g., of safe distances) through the implementation of safety and decision-making processes at an individual level. Furthermore, information relevant to the determination of appropriate safety distance can be garnered through the stereoscopic capturing and processing of images capabilities of rear cameras.

6.3. Smart Transport Infrastructure

City transport infrastructure, as well as vehicles and the user interaction with them, are being transformed by digital technologies. Intelligent transportation systems (ITS) is the collective term which comprises all smart infrastructure technologies, technologies which are being embedded in traffic lights, car parks, roads, bridges, and toll-booths to make them capable of communicating with one another and with vehicles. The benefits granted by these innovations are manifold: the resulting transport infrastructure system will sport less congestion, higher safety, and will be predictively maintained.

As roads share space with people and vehicles, a variety of transport-related activities could be recognized and monitored through sensors integrated into road infrastructure, in the same manner that IoT and IoS (Internet of Space) leverage applied sensor technology.
The European Commission's action plan for the deployment of intelligent transport systems - the "ITS action plan" - aims at reducing the environmental impact of road transport and its interfaces with other transport modes. The definition of European standards (e.g., for data exchange) serve as a necessary means to this end. Moreover, the EU promotes intermodal transportation to reduce congestion and greenhouse gas emissions, make roads safer and decrease energy consumption.

Over 80% of the world's greenhouse gas (GHG) emissions are due to emissions generated by urban-related production and consumption. Pollution severity in some cities force their citizens to restrain from engaging in outdoor activities and using vehicles. Nowadays, finding an energy supply which directly involve mobility systems has become a priority. Modifications in modes of transportations, travel rout and the integration of real-time information can result in optimal average car speed and improved traffic flow.

Highly networked transport systems could be designed to work more like an ecosystem than a mechanism, thus relying more on local rules than on top-down control. This would better leverage an environment with rich feedback between vehicles and the infrastructure on which they rely, taking full advantage of intelligent assets in applying circular economy principles and contributing to find even more innovative and comprehensive smart city solutions.

A circular economy is similar to an ecosystem in that it is not subject to a pervasive controlling influence and heavily relies on feedback. The flows of information generated may be exploited to make a transport system more circular. Traffic lights, in particular, could serve as an example. As Helbing and Laemmer show, digital sensing and communication technologies can be integrated into a set of traffic lights to allow car to control the lights rather than the opposite, thus reducing average delay times by up to 40%. This results from traffic being a complex adaptive system, which can be effectively managed by making each set of lights behave in accordance with some simple 'bottom-up' rules (e.g., recognising 'platoons' of incoming cars and prioritizing their passage), and by letting the system autonomously reach a dynamic equilibrium.

Even state of the art mechanisms which control light sequences in a 'top-down' fashion still rely on average rather than actual traffic patterns (this happens even when rush hours are taken into account). Consequently, they cannot but be outperformed by the simple rule approach. This is because the sheer complexity of the system as a whole is simply for real-time optimization: even a supercomputer could not manage to perform all the necessary computations. Moreover, shock cannot be tackled as effectively as with the simple rule approach.

Also two-wheeled vehicles could benefit from this strategy. For instance, Copenhagen is installing 380 smart traffic signals capable of prioritizing the progress of cyclists through traffic, thus speeding up their commutes (in Copenhagen, 50% of all residents commute by bike). Platoons of bikes approaching an intersection can be detected by sensors and be allowed through by turning the lights to green, process which can be replicated along specific routes, eventually creating an uninterrupted journey, using the data from cameras to fine-tune the lights timings by estimating the cyclists' speed. It is expected that travel times will be reduced by 10% and the number of commuters will increase.

The increasing flow of information could eventually make even smart traffic signals altogether obsolete in the future, even if they outperform pre-programmed ones. In fact, modelling by the MIT Sensable Lab has shown that a slot-based system could merge information sent by self-driving cars equipped with a variety of sensors, effectively creating autonomous intersections which would be superior to traffic lights of any sort. Streams of vehicles would be accurately directed, and the number of cars safely using an intersection over a given period could be possibly doubled.

Bottom up rules and data flows could also be used to increase safety. Traffic lights could be equipped with collision avoidance systems to allow them to recognize an imminent crash between two vehicles on the basis of their trajectories, and consequently warn drivers or even activate the vehicle's brakes.

Even speed limits can benefit from the application of bottom up rules. As we will see in the next sections, Intelligent Speed Adaptation could correlate information a digital speed limit map with a vehicle's position over time to help a driver keep the limit (e.g., by using traffic signals to warn the driver), or to directly adjust the vehicle's speed (e.g., by automatically slowing down a self-driving car). For example, France has developed an ISA system capable of using traffic signals to automatically slow down fast-moving vehicles in extreme weather conditions.

6.4. Intelligent Speed Adaptation

Excessive speed can not only be the cause of accidents, but also defines the level of impact; thus, it can be considered as a contributory factor in road accidents.
Any system that did not allow the vehicle to exceed the safe or legally enforced speed is referred to as an Intelligent Speed Adaptation (ISA). Their support aims at helping the driver maintaining a legal and safe speed along the driving time. Essentially, ISA systems automatically slow down vehicles and/or alert the driver involved in a speeding situation.
ISA intervention can be varied [34]:

- network-related information such as areas requiring lower speeds, network conditions (e.g., related to weather, traffic density, incidents) could be incorporated into speed limit information to extend its informative content;
- as to the level of intervention, ISA can be advisory (the driver only receives alerts on limits and violations), voluntary (the system can control the vehicle but its activation is up to the driver), or mandatory (the driver has no control over the ISA interventions)

Recently, interest on ISA has increased among the scientific community. Moreover, many different European countries have taken actions to increase road safety.
In [35] a variety of speed management strategies and their effects have been systematically identified; among those reported in the study, speed cameras, engineering schemes, ISA, speed limits and zones, vehicle-activated signals and integrated strategies were the most common. Several speed management strategies were reported to have positive effects. The strategies' selection process mainly relies on the road characteristics, the driver's attitude about the strategy, economic and technological capabilities of the country and, as a crucial factor, political support.

In [36] the authors presents a process to determine the speed limit values by matching a vehicle real road-network position with a map and a database. A predictive model of movement is combined with an In-of-Order Kalman filter in order to, respectively, limit instants without informations and corrects the GPS measurements taking into account variable sampling times. The model also includes an online map-matching algorithm based on several weighting parameters.

The paper [37] reports research involving three cost-benefit analyses performed on different ITS schemes (Active Traffic Management, Intelligent Speed Adaptation and the Automated Highway System) on M42, one of the UK's busiest highways. The environmental scope of the assets involved is widened to consider the possibility of new technology linked by ICT and located within multiple spatial regions. Data centre energy emissions, the embedded emissions of the road-side infrastructure, vehicle tailpipe emissions, additional hardware required by the vehicles (if applicable) and safety, and all aspects of sustainability were the aspects which the study focused on.

Bad driving behavior is at the root of over speeding violations. Nowadays, traffic rules are frequently violated. The development of a new system capable of effectively detecting speed violations on the road, and supporting the driver to observe traffic rules has been the subject of the article [38]. In the proposed system, the drivers is warned while driving by keeping the speed below the speed limit prescribed by a specific area and an alerting, recording and reporting system for over speeding vehicles is integrated into it. The system uses the ZigBee technology, previously described in section 4.6.1. The main benefit which comes with using this system is that in the case of speeding vehicles not being controlled by the driver, the system takes control of the vehicle automatically thus avoiding potential crashes.

GreenDrive is another project which is focused on ISA [39]. Developed by the University of Illinois, GreenDrive can help drivers save fuel by judiciously advising on driving speed to match the signal phase and timing (SPAT) of upcoming signalized traffic intersections. In the absence of such advice, the default driver behavior is usually to accelerate to (near) the maximum legally allowable speed, traffic conditions permitting. This behavior is suboptimal if the traffic light ahead will turn red just before the vehicle arrives at the intersection. GreenDrive uses collected real-time vehicle mobility data to predict exact signal timing a few tens of seconds ahead, which allows it to offer advice on speed that saves fuel by avoiding unnecessary acceleration that leads to arriving too soon and stopping at red lights. GreenDrive differs from previous work in three respects. First and most importantly, a more challenging scenario is tackled, where some phases (such as left-turn arrows) are added or skipped dynamically, in accordance with real-time traffic demand. Second, the approach used can accommodate a low system penetration rate and low vehicle density. Third, GreenDrive treats user-specified travel time requirements as soft deadlines and chooses appropriate speed adaptation strategies according to the user time budget. Using SUMO traffic simulator with real and large-scale road network, it is shown that GreenDrive learns phase durations with an average error below 2s, and reduces fuel consumption by up to 23.9%. Real-world experiments confirm 31.2% fuel saving and the ability to meet end-to-end travel time requirements.

7. IoT applications on mobility

7.1. Project Sheets

In this section we present a set of relevant projects concerning IoT applications on mobility. For each project, we provide a project sheet with the following information: Project Name, Official Website, Led by, Start date, End date, Context, Budget, Funding, Contacts, Pilot sites, Main Goal, Objectives, Key Technologies, Motivations, Relevant Outcomes.

Project Name: COMPASS4D

Official Website: http://www.compass4d.eu/

Led by: ERTICO (Giacomo Somma, g.somma@mail.ertico.com)

Start date: January 2013

End date: December 2015

Context: Cooperative Intelligent Transport Systems (C-ITS)

Budget: €9.996.000

Contacts: g.somma@mail.ertico.com

Pilot sites: Newcastle, Copenhagen, Helmond, Verona, Bordeaux, Vigo, Thessaloniki

Figure 9 - Pilot sites

Description: Compass4D focused on three services which will increase drivers' safety and comfort by reducing the number and severity of road accidents, as well as by optimising the vehicle speed at intersections and by possibly avoiding queues and traffic jams. The three services are: the Energy Efficient Intersection (EEI), the Road Hazard Warning (RHW) and the Red Light Violation Warning (RLVW). Compass4D services have also a positive impact on the local environment by enabling the reduction of CO_2 emissions and fuel consumption for equipped vehicles.

As the focus of Compass4D is on actual deployment, these services have been implemented through a combination of established technologies and available pre-commercial equipment. Dedicated short-range communication (ITS-G5) and cellular networks (3G/LTE) have been used, following ETSI TC ITS standards. In addition, Compass4D has identified solutions to deployment barriers and elaborated business models to make the services self-sustainable for a wide commercialisation. This work includes cooperation with standardisation organisations and global partners to achieve interoperability and harmonisation of services.

The Compass4D services have been piloted during one year in seven cities: Bordeaux, Copenhagen, Helmond, Newcastle, Thessaloniki, Verona and Vigo. Prior to the pilot operations, the implementation phase lasted more than one year and was a result of teamwork involving all consortium partners. Overall, during the three years of the project duration, Compass4D has installed equipment and implemented cooperative services on almost 300 road side units and traffic lights and on more than 600 vehicles, with over 1200 drivers involved in the pilot operation.

Main Goal: Compass4D focused on three services which will increase drivers' safety and comfort by reducing the number and severity of road accidents, as well as by optimising the vehicle speed at intersections and by possibly avoiding queues and traffic jams.

Key Technologies: 3G/LTE, on-board units (OBUs) and road-side units (RSUs) based on dedicated short-range communication technologies (ITS-G5).

Motivations: issues such as number and severity road accidents, queues, traffic jams.

Relevant Outcomes: three services: the Energy Efficient Intersection (EEI), the Road Hazard Warning (RHW) and the Red Light Violation Warning (RLVW). Overall, during the three years of the project duration, Compass4D has installed equipment and implemented cooperative services on almost 300 road side units and traffic lights and on more than 600 vehicles, with over 1200 drivers involved in the pilot operation.

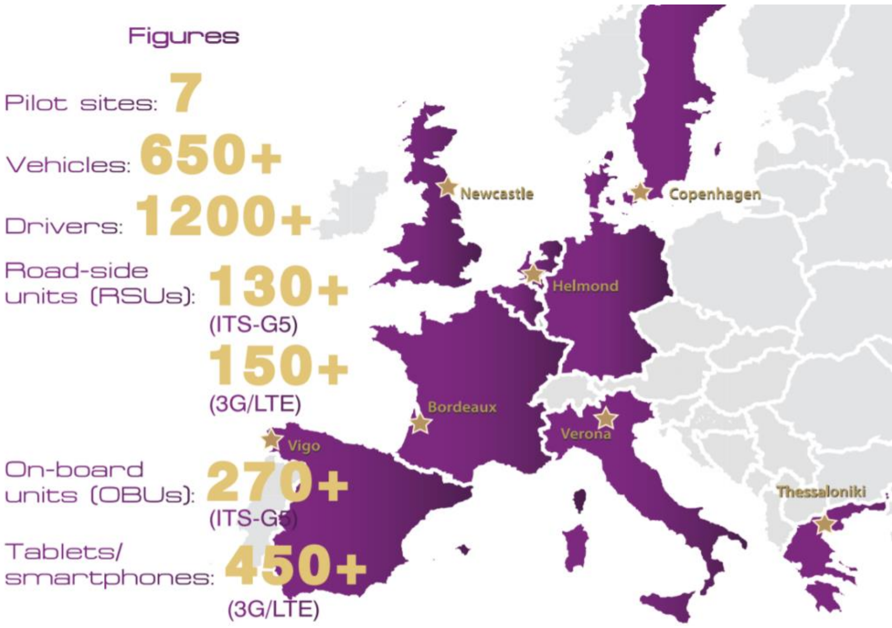


Figure 10 – COMPASS4D project main figures

The pictures above show time-to-green (left) and speed advice for green phase – GLOSA (right) in Verona.

The pictures above show the HMI display combining in a map the RHW and EEIS services, with countdown of the time-to-green or time-to-red at equipped intersections in the city of Vigo.

Display change from EEIS (left) service to RHW (right) service in Vigo.

MOBiNET

Project Name: Europe-Wide Platform for Connected Mobility Services (MOBiNET)

Official Website: http://mobinet.eu/

Led by: Rasmus Lindholm, ERTICO ITS Europe. The consortium includes 33 partners, among them: CRF (Centro Ricerche Fiat), Volvo, Transport for London, Allianz, Xerox, Tim (see full list at http://mobinet.eu/?q=content/consortium)

Start date: 1 November 2012

End date: June 2017

Context: e-market place of mobility services

Budget: €15.6 million

Funding: €11 million (EU)

Contacts: info@mobinet.eu

Pilot sites: Aalborg, Helmond, Helsinki, London, Torino, Trikala, Trondheim, Vigo

Main goal: MOBiNET envisages a new "Internet of Mobility" where transport users meet providers of next-generation mobility services. MOBiNET will open the door to harmonised services, seamless connectivity, instant access to transport data, single subscription and billing for travellers and a one-stop shop for mobility services.

Description: MOBiNET is a European e-marketplace of mobility services for business and end users. At the core of MOBiNET is a platform providing components and tools that enable interactions between users and suppliers of mobility services.

The MOBiNET e-marketplace allows content and service providers to exchange transport and mobility services for new or third-party service development.

MOBiNET provides:

- ✓ A comprehensive Europe-wide directory of mobility and transport-related data and services
- ✓ An e-marketplace as an e-commerce network linking content providers, service providers and end users
- ✓ Traveller assistance tools for service roaming and virtual ticketing
- ✓ Third-party service composition to discover and add content and services to existing products
- ✓ An "App Directory" and smart Communication Manager for end-user devices
- ✓ A Service Development Kit to enable easy creation of new user services

Figure 11 - MOBiNET e-marketplace

Motivations: The project addresses the current frustration that widespread deployment of ITS services is hindered by the complexity of the real world of mobility information and infrastructure, which e.g. prevents seamless coverage of services across borders throughout Europe.

Relevant Outcomes: The MOBiNET concept includes **five key areas of innovation**:

- ✓ Federated **directory of all European online services** for transport and mobility;
- ✓ **Identity authentication and management** scheme for single sign-on by any user for multiple services;
- ✓ **Unified accounting & billing framework**, allowing roaming by users & payment clearing between providers;
- ✓ Secure **operating environment for in-vehicle and portable devices**, offering (for users) a dedicated app-directory and (for service providers) access to all subscribing users;
- ✓ **B2B community & marketplace** for automatic negotiation of service agreements when adding extra service components and data sources to existing service offerings.

Key technologies: 3G/LTE.

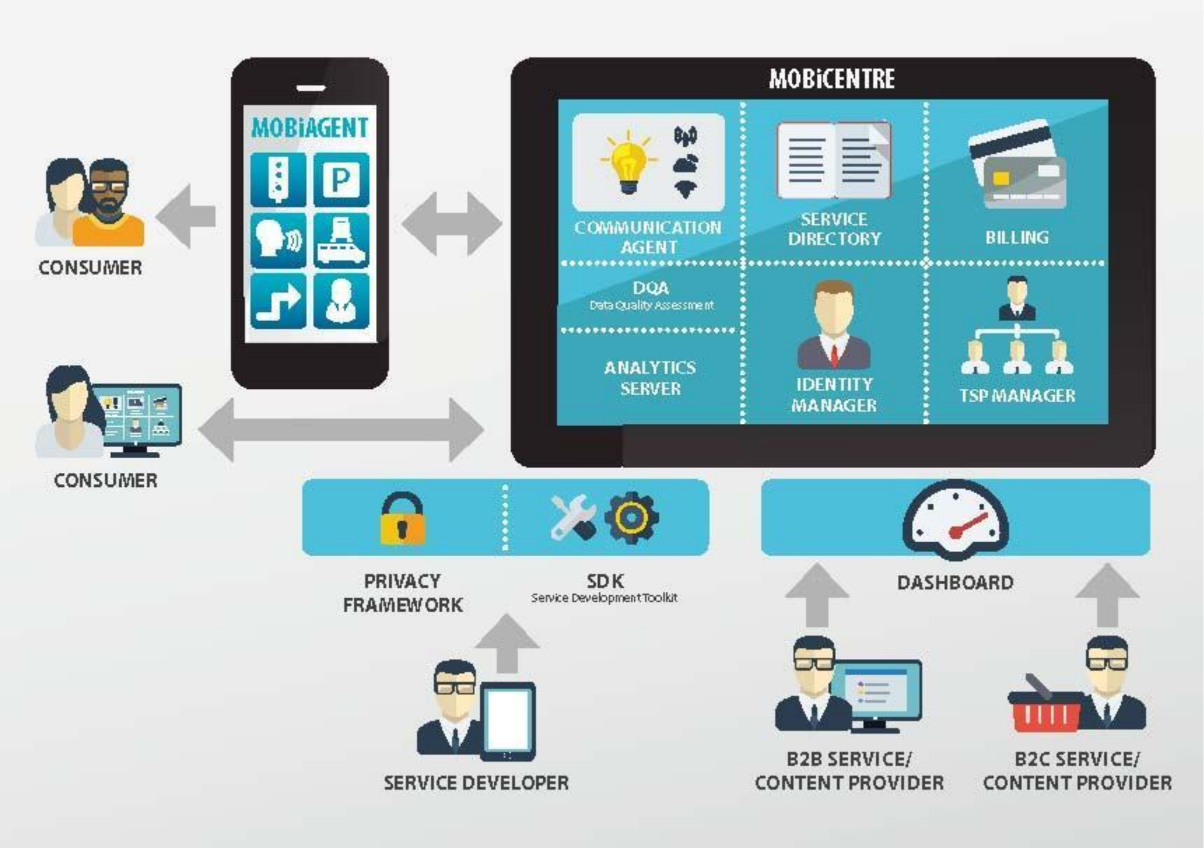


Figure 12 - The platform

TEAM

Project Name: TEAM

Official Website: http://www.collaborative-team.eu/

Led by: Fraunhofer-Institut FOKUS. The consortium counts 28 partners, ranging from car manufacturers to telecommunication providers, research institutes, road infrastructure operators, traffic managers and more.

Start date: November 2012

End date: October 2016

Context: collaboration between travellers, drivers, and road infrastructure operators

Budget: €17.1 million

Funding: €11.1 million (EU)

Contacts: ilja.radusch@fokus.fraunhofer.de

Pilot sites: within the EU (Trikala among them)

Main Goal: The vision is to use mobile devices such as smartphones to significantly improve transportation safety and efficiency, implementing environmental aspects. This includes contribution towards the objective of reducing fatalities in the EU, not only addressing drivers but all road users – including passengers and pedestrians. In this way, drivers, travellers and infrastructure are meant to act as a team, adapting to each other and to the situation, creating optimised mobility conditions.

Description: The European Union supports this collective research with a co-funding. TEAM stands for Tomorrow's Elastic Adaptive Mobility. TEAM turns static into elastic mobility by joining drivers, travellers and infrastructure operators together into one collaborative network. Thereby TEAM explicitly takes into account the needs and constraints of all participants and the network itself. The success of the project will be demonstrated and validated via innovative applications for end-users and a Europe-wide mobility experiment to illustrate the systems' benefits in a pan-European setting.

Key Technologies: 4G LTE, cloud, IEEE 802.11p (for V2X communication in the licensed ITS band of 5.9 GHz).

Motivations: lack of collaboration between travellers, drivers, and the road infrastructure operators.

Relevant Outcomes: 11 applications, which can be seen at http://www.collaborative-team.eu/overview/apps

Array of Things

Project name: Array of Things

Official Website: https://arrayofthings.github.io.

Led by: Argonne National Laboratory

Start date: 2013

End date: not defined

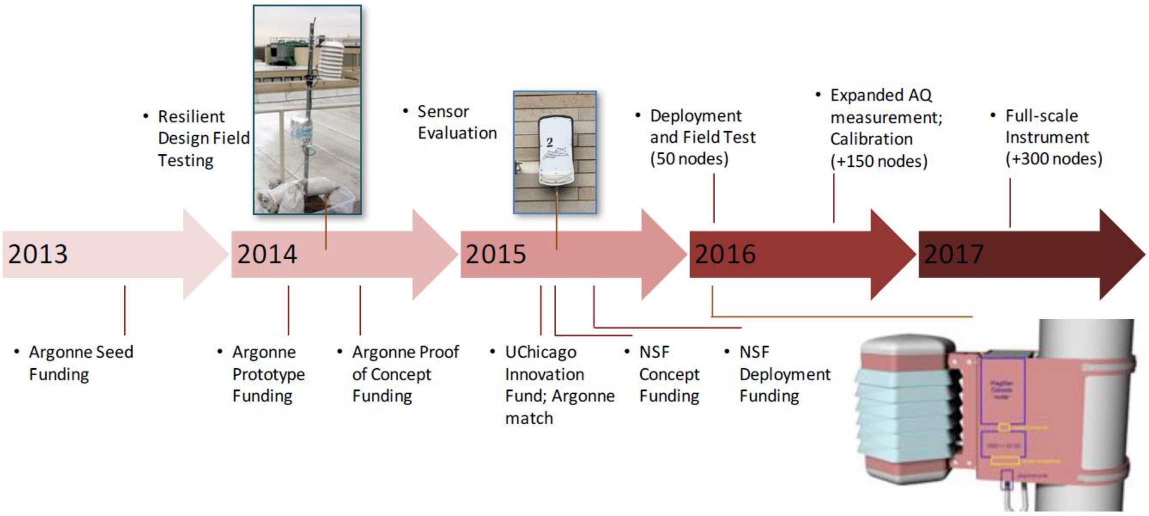


Figure 13 - Project timeline

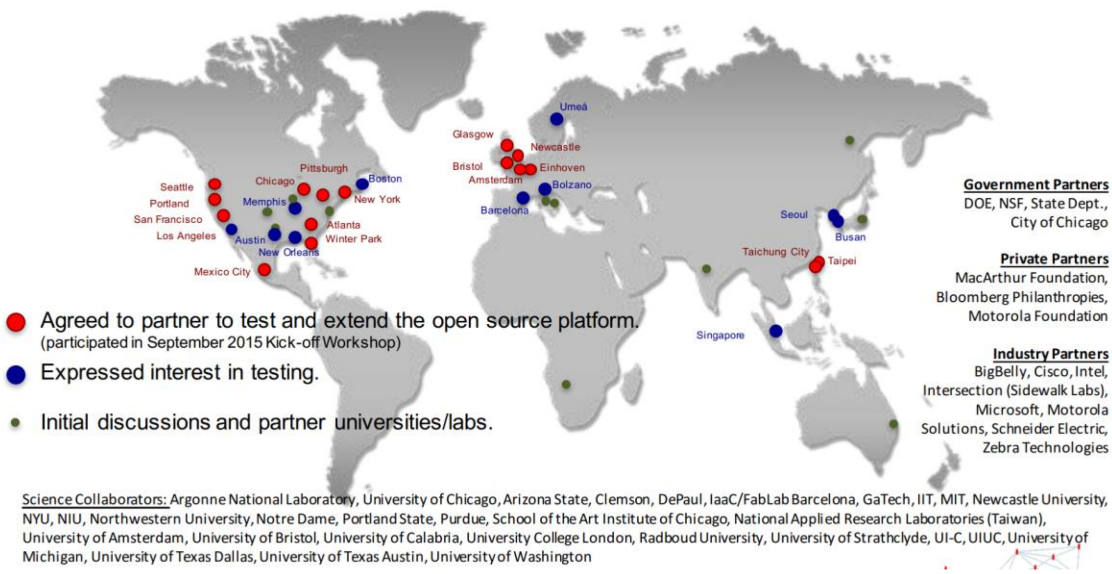
Context: urban sensing.

Budget: $6 million

Funding: $6 million ($2 million from Argonne National Laboratory, $4 million grant funding from the National Science Foundation, the University of Chicago, and other sources)

Contacts: aot@uchicago.edu, @arrayofthings (Twitter), Facebook.

Pilot sites: Most in USA and EU



Key technologies: 3G/LTE, open data (all data are available on the hub for open datasets plenar.io (http://docs.plenar.io).

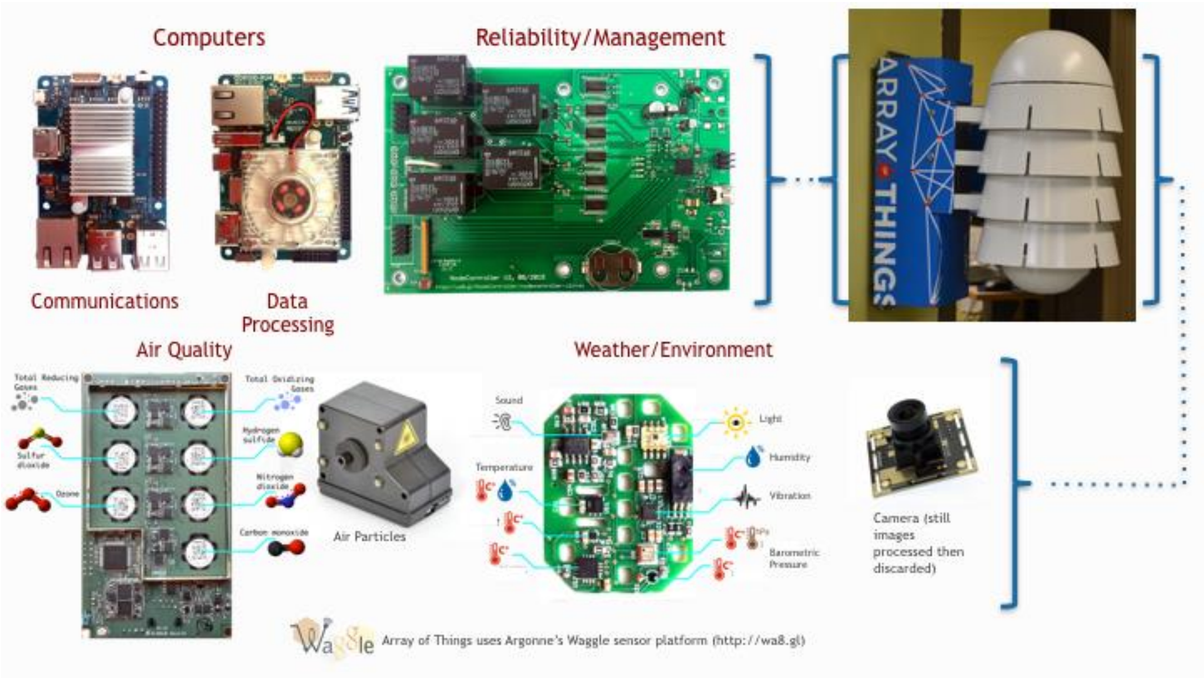


Figure 14 - Current AoT Node Architecture

Main Goal: AoT will provide real-time, location-based data about the city's environment, infrastructure and activity to researchers and the public. This initiative has the potential to allow researchers, policymakers, developers and residents to work together and take specific actions that will make Chicago and other cities healthier, more efficient and more livable. The data will help make Chicago a truly "smart city," allowing the City to operate more efficiently and realize cost savings by anticipating and proactively addressing challenges such as urban flooding and traffic safety.

Because the data will be published openly and without charge, it will also support the development of innovative applications, such as a mobile application that allows a resident to track their exposure to certain air contaminants, or to navigate through the city based on avoiding urban heat islands, poor air quality, or excessive noise and congestion.

Description: The Array of Things (AoT) is an urban sensing project, a network of interactive, modular sensor boxes that will be installed around Chicago to collect real-time data on the city's environment, infrastructure, and activity for research and public use. AoT will essentially serve as a "fitness tracker" for the city, measuring factors that impact livability in Chicago such as climate, air quality and noise.

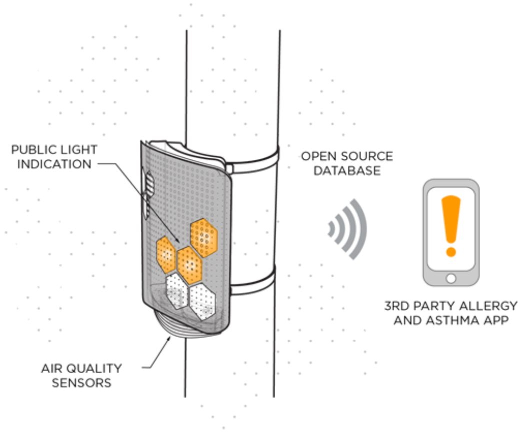


Figure 15 - Example of use of open data by a 3rd party application

Data collected by AoT will be open, free, and available to the public. The nodes will transmit data to a secure central database server at Argonne National Laboratory. Data will then be published openly to allow individuals, organizations, researchers, engineers and scientists to study urban environments, develop new data analysis tools and applications, and inform urban planning. Raw data will also be posted to the City of Chicago's open data network and Plenario, a web-based portal that supports open data search, exploration, and downloading with open datasets from Chicago and around the world.

In addition, software, hardware, parts, and specifications will also be published as open source, to encourage participation and oversight from the developer community and public. The node architecture is shown in Figure.

All hardware, software and data being collected will be regularly reviewed by a Technical Security and Privacy Group chaired by Von Welch, director of Indiana University's Center for Applied Cybersecurity Research. Operating as an external, independent review team, the committee will also be consulted whenever there is a request for a new kind of data to be collected.

The Array of Things Executive Oversight Council will be co-chaired by Commissioner of the City's Department of Innovation and Technology Brenna Berman, Urban Center for Computation & Data Director Charlie Catlett, with additional members selected from academia, industry, non-profits, and the community. No data will be monitored without the approval of the privacy and security external oversight committee, the City of Chicago and the AoT executive committee, and the operation of the Array of Things will be governed by privacy policies that will be published prior to installation of nodes.

In partnership with the City of Chicago, the nodes will be mounted on streetlight traffic signal poles around the city, beginning in Summer 2016, with 500 nodes installed by the end of 2018. The Array of Things team will work with several partners, including the City of Chicago's Department of Information and Technology and Department of Transportation, researchers, neighborhood groups and community members, to determine the best locations for the deployment of AoT.

The Array of Things project is led by Charlie Catlett and researchers from the Urban Center for Computation and Data of the Computation Institute, a joint initiative of Argonne National Laboratory and the University of Chicago. The underlying software and hardware design, known as Waggle, was developed at Argonne National Laboratory by Pete Beckman, Rajesh Sankaran, and Charlie Catlett. The custom enclosure for the sensor nodes was developed by Product

Development Technologies, based on early designs from Douglas Pancoast and Satya Mark Basu of the School of the Art Institute of Chicago. The project is executed in partnership with the City of Chicago.

The Array of Things project also involves partnerships with scientists at academic institutions including Northern Illinois University, University of Illinois at Chicago, University of Illinois at Urbana-Champaign, DePaul University, Illinois Institute of Technology, Purdue University, University of Notre Dame, Arizona State University, the Santa Fe Institute, University College London, Clemson University, and the Institute for Advanced Architecture of Catalonia. AT&T is the project's communications partner, providing all AoT connectivity for Chicago. Technical advice and support comes from a growing number of industry partners including Cisco, Microsoft, Schneider Electric, Intel, Motorola Solutions, and Zebra Technologies.

Array of Things is funded by the National Science Foundation, the Chicago Innovation Fund, and Argonne National Laboratory.

Motivations: The AoT project tries to answer the following questions: What if a light pole told you to watch out for an icy patch of sidewalk ahead? What if an app told you the most populated route for a late-night walk to the El station by yourself? What if you could get weather and air quality information block-by-block, instead of city-by-city?

Relevant Outcomes: Potential applications of data collected by the Array of Things include:

- ✓ Sensors monitoring air quality, sound and vibration (to detect heavy vehicle traffic), and temperature can be used to suggest the healthiest and unhealthiest walking times and routes through the city, or to study the relationship between diseases and the urban environment.
- ✓ Real-time detection of urban flooding can improve city services and infrastructure to prevent property damage and illness.
- ✓ Measurements of micro-climate in different areas of the city, so that residents can get up-to-date, high-resolution "block-by-block" weather and climate information.
- ✓ Observe which areas of the city are heavily populated by pedestrians at different times of day to suggest safe and efficient routes for walking late at night or for timing traffic lights during peak traffic hours to improve pedestrian safety and reduce congestion-related pollution.
- ✓ Array of Things data and technology will also be available for educational purposes, engaging local students and training them on important job skills(see Lane of Things).

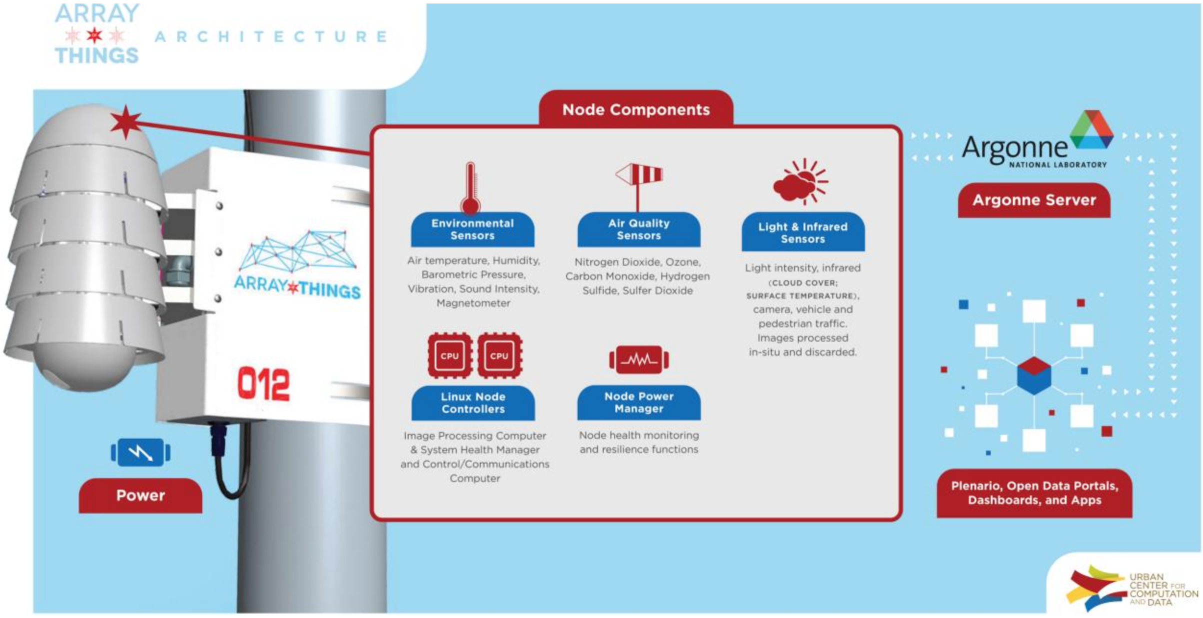


Figure 166- Architecture

oneTRANSPORT™

Project name: oneTRANSPORT™

Official Website: http://www.interdigital.com/solution/onetransport

Led by: InterDigital Europe. The consortium includes 11 partners: Arup, InterDigital Europe, Buckinghamshire County Council,Clearview Traffic Group, Hertfordshire County Council, Highways England, Imperial College London, Northamptonshire County Council, Oxfordshire County Council, Traak Systems and World Sensing.

Start date: 2014

End date: 2026

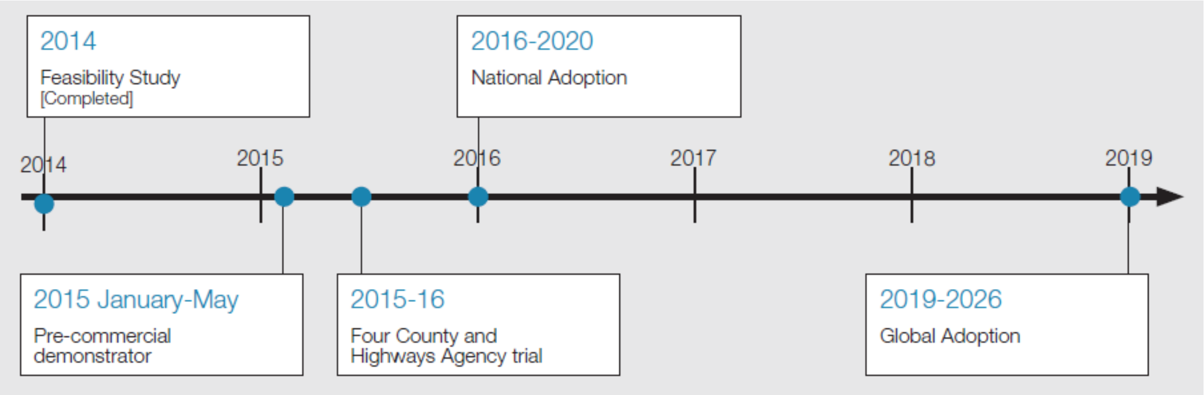


Figure 17 - Project timeline

Context: smart city and transportation

Budget: £3.5 million

Funding: Part of the £3.5 million funded by Innovate UK

Pilot sites: UK

Main Goal: Enable data publishers, data subscribers, service and application providers. Operate a commercial marketplace (technology, agreements, user guides). Integrate data sources and provide training and access. Log transactions, reconcile data consumption, billing and payments.

Description: The Innovate UK-sponsored oneTRANSPORT™ in-field trial, supported by a growing ecosystem, is reaching its conclusion in November 2017. The oneTRANSPORT Data Marketplace is being prepared by InterDigital to operate as an open commercial service.

The oneTRANSPORT Data Marketplace is an open, standards-based environment that both public and private sector organizations are using to publish their data, where it can be discovered, consumed and used in any kind of application or service.

Data owners can "publish once, distribute to many". Organizations can: consume city and transport-related data that was previously inaccessible or too siloed; distribute and gain access to both static and real-time data via an open, cloud-based platform; discover and consume any data via a single interface with terms that support the open use of data; as the platform does not require exclusivity or copyright to published data, the organizations can use and distribute their data through the means they prefer.

The oneTRANSPORT Data Marketplace enables integrated operations and efficient use of infrastructure. New services can be enabled that facilitate the movement of people and goods and improve quality of life. The Marketplace supports connections with public and private data systems and is especially suitable for data from sensor networks and the Internet of Things. Securely stores published data and makes it available through open APIs that conform to the global oneM2MTM international standard. Facilitates collection of access fees for data publishers while also enabling free data distributions where applicable.

Key Technologies: open data (static and real-time), cloud, IoT devices (e.g. sensor networks).

Motivations: city budgets are under pressure in absolute terms and in relation to budgetary ring-fences around education, health and welfare services. The financial squeeze led many of the early smart city projects to tackle quick-win, point solutions with a clear, near-term return on investment.

City managers are beginning to see that their initial focus on quick-win, standalone solutions is costly to maintain and difficult to integrate into a unified smart city operating framework. The strategic challenge is to recognize that each city will manage a growing number of connected assets and data sources. The start-up challenge is to experiment by bringing together a few data streams into a common environment to enable data sharing and application mashups for different use cases. Technology can overwhelm the start-up process and lead to inaction or investment in just a sub-set of the overall portfolio necessary to sustain multiple smart city services.

One approach to overcome the technology challenge is to work within a multi-party eco-system. Here, different specialists contribute their relevant expertise within the framework of a common goal and model of cooperation. Such an approach combines the best of the public and private sectors.

Relevant Outcomes: Data Marketplace Platform.

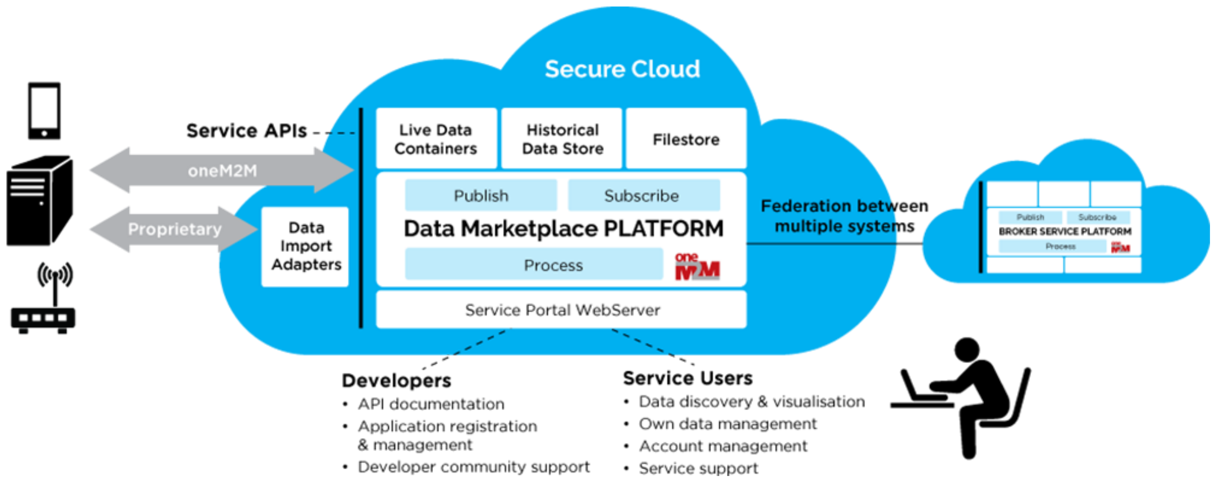


Figure 18 - The Data Marketplace Platform

Informed Rural Passenger

Project name: Informed Rural Passenger

Official Website: http://www.dotrural.ac.uk/irp/

Led by: University of Aberdeen

Context: rural transport environment

Area/Region: UK

Main Goal: create a transport information ecosystem within which it is possible to explore issues such as data provenance, reliability of passenger-sourced information, and travel behaviour change.

Description: Informed Rural Passenger aims to review the state-of-the-art in journey planning and passenger information systems including public and other shared transport modes; establish user information requirements for the journey planning process in rural contexts; design semantic models to underpin the rural passenger information ecosystem, including capturing provenance; develop a prototype cloud-based platform for a rural passenger information ecosystem, associated knowledge layers and scalable query/reasoning capabilities; create prototype services that utilise the knowledge and information components of the ecosystem to support real-time information and community content construction; apply user-centred approaches to develop novel user-interface modalities for communicating travel information via mobile and desktop clients; develop a component that assess the quality of information utilising the ecosystem knowledge and information components; evaluate the system in a trial area, including measurement of changes in travel behaviour in response to customised travel information.

Key Technologies: 3G/LTE, linked open data, cloud platform.

Motivations: in rural areas, a possible underlying lack of potential solutions to develop travel information services often cause journey planning scenarios to not be included due to missing or inaccurate data.

Relevant Outcomes: Software: GetThere app (not available anymore); Intelligent Information Infrastructure / Ecosystem.

Social Journeys

Project name: Social Journeys

Official Website: http://www.dotrural.ac.uk/socialjourneys/

Led by: University of Aberdeen

Context: rural transport environment

Area/Region: UK

Main Goal: Exploring how social media updates can be combined with existing (open) datasets to further enhance real-time passenger information.

Description: Social Journeys aims to understand how social media is currently used for real time passenger information by identifying potential user groups in the passenger landscape; apply user-led design methods to inform novel approaches for the use of social media; create and evaluate bespoke travel information solutions via design workshops suited to the particular needs of users; incorporate social media data into the broader public transport ecosystem; understand the quality and trust issues associated with social media data; Investigate methods to deal with inconsistencies between different data sources – whether these arise from errors, malicious behaviours, etc.; deliver services that rural travellers will want to use, and that operators/local authorities will want to host.

Key Technologies: 3G/LTE, linked open data.

Motivations: There has been a rapid growth in the use of social media in public transport in recent years. Public transport service providers currently communicate with customers via social networks such as Twitter. This benefits transport operators as they can gain insight into customer attitudes and behaviours. It also enables passengers to be alerted to delays and disruption at an early stage through the existing channels they use.

Relevant Outcomes: nothing relevant.

On-the-go / Rural Mobility 2.0

Project name: RAMSES-Platform, on-the-go-rural mobility 2.0

Official Website: http://www.ruralmobility.eu/

Led by: Berlin University of Technology, Dept. Work and Technology , Marchstrasse 23 (MAR 1-1), D-10587 Berlin

Context: rural transportation services

Area/Region: German state of Baden-Württemberg

Key Technologies: 3G/LTE.

Main Goal: Empowering rural mobility by linking public transportation services, alternative mobility providers and rural communities together on one platform.

Description: The RAMSES on-the-go platform provides not only an intermodal trip planner and ticketing for users of rural transportation services but also specifically aims at empowering small-scale providers of mobility services in rural areas, e.g. voluntary community transport providers. A low cost, integrated solution supports them in organizing, operating and marketing their services. From the point of view of the advantage to the society, the platform provides access to a wider range of mobility options, better integration, and consequently less dependence on cars and lower environmental impact.

Motivations: Public transportation in rural areas needs to cope with structural difficulties of low population densities, high car ownership and an aging rural society. But rural areas are also characterized by vibrant community life, strong voluntary engagement and collaboration. Local voluntary organizations in many European countries, including Germany, have started to operate community transport services to their villages. The number and types of services is growing steadily. RAMSES is taking these rural mobility services to the next level. Community-driven transportation and other alternative mobility options like bottom-up car sharing rely mostly on face-to-face contact, personal acquaintance and trust; it is largely paper-based, as restricted budgets do not allow implementing IT infrastructure. Building on this first generation of the sharing economy, RAMSES offers an easy-to-use IT application that allows providers to make the most of the local commitment.

Relevant Outcomes: The digital platform “on-the-go”, which comprises on-demand, peer-to-peer, scheduled and non-scheduled services.

In rural areas, mobility providers often lack digital tools to manage and promote their services. on-the-go offers support via an IT-based mobility platform with smartphone interface.

Components of the platform are:

- ✓ Routing assistant
- ✓ Multimodal trip planner
- ✓ Driver shift planning
- ✓ Vehicle and fleet management
- ✓ Accounting
- ✓ Monitoring
- ✓ Communications

8. Opportunities

The evolution fostered by IoT applications will make different types of data collection easier, more accurate, and in real-time. Moreover, new types of remote control and automation will be devised. These developments bring about new opportunities for nearly all aspects of public transport, including [40]:

- ✓ Planning: opportunities of interest to strategic transport planners.
- ✓ Operations: opportunities of interest to operators.

In the following sections, we will focus on these two types of opportunities, enabling new smart mobility paradigmas, and we will consider the different impacts of their application in urban vs. rural contexts.

8.1. Planning

Effective resource planning must ensure resources are best employed to provide the best possible services to the travelers and to minimize the transport-related negative effects (e.g., CO2 emissions, noise). This is a major challenge in public transport, as it requires to tackle possibly complex issues such as devising bus and train routes (or lines), determining frequencies and timetables of the vehicles travelling along the routes, and localization of stops. Other issues concern decisions on implementing new technologies, such as ITS services in public transport. The lack of information feedback from transport operations is among the main reasons why planning is not an easy task. In fact, transport planners are not always provided with all the information they need, which, for instance, do not allow them to optimize transport resources planning in the best possible way in case data on individual trips is not sufficient. Collecting huge amounts of data, ranging from travel behavior to infrastructure usage, is possible by increasing the use of IoT-based services in transport operations. This represents a unique opportunity for transport planners to achieve optimal public transport resources utilization (e.g., vehicles and infrastructure use).

One of the most common strategies to provide transport planning decision-making support is transport modeling and simulation. This approach can, for instance, provide tools to predict the effects of infrastructure investments and new transport policies. A simulation model could require different types of data, ranging from socio-demographic information to the transport network data. In addition, transport system modeling and simulation gives the opportunity to access data automatically collected (e.g., by IoT devices) and to use open web services like Google Maps to perform computations that traditionally are performed by the simulation model.

8.1.1. Examples of opportunities

IoT systems, smartphones, and crowdsourcing systems give transport planners the opportunity to gain access to more accurate data, and/or new types of data. Among the tasks which could benefit from the use of the data thus collected, is the optimal bus routes and timetables planning, which could be more effectively carried out than it is usually possible today.

Collection of traveler data. Movement patterns of smartphone owners can be easily extracted with applications, and leveraged to identify, among other things, the chosen transport mode (e.g., car, bus, bike, walking) [47]. Other types of data that may be similarly obtained are the transport services used by individual travelers, and the time when they start or stop using services. Such data may be employed to increase sustainability, by enabling for improved transport resources utilization. An example of such possible improvements lies in supporting the identification of more efficient routes, which should eventually result in reduced emissions from public transport vehicles (i.e. direct emissions reduction). Benefits to other sustainability issues are possible, according to the aspects of interest in the route design process, such as accessibility, coverage, and travel time. Improved routes provide also the possibility of reducing indirect emissions. Nevertheless, this is expected to how many travelers who traditionally choose the private vehicle alternative are attracted by improved public transport routes, enabled through the use of travel data, and how often they decide to opt for the public transport alternative on the basis of such improvements.

Collection of vehicle data. IoT brings about benefits even on from the vehicle data collection perspective. IoT makes it possible to automatically retrieve detailed travel data on aspects such as the time when passengers enter and leave vehicles, occupancy rates (e.g., through sensors which detect the available seats), and robustness (frequent delays). Planning of the resources used in public transport might be improved to the benefit of travel planners by leveraging realistic and high quality data of the abovementioned types. through Through collecting information about the current use of vehicles, improvements in resource utilization and direct emissions reduction can be achieved (e.g., by using mini-buses at times where few travelers are expected). Public transport might, however, become less attractive if vehicle data is used to favour the deployment of excessively small buses. Nevertheless, designing more attractive services could lead to even higher indirect emissions reduction, for instance, by deploying extra buses when the buses are typically crowded.

Collection of traffic data. Measuring congestion levels via crowdsourcing and road-side cameras is an example of online traffic monitoring [48]. This strategy might provide input which can be employed to reduce the direct emissions and public transport travel times, for instance, by providing a means to avoid congested roads through the generation of improved routes. Public transport could also be made more attractive by using traffic data to design ad-hoc services along routes which are usually subject to heavy congestion issues (e.g. introducing bus lanes) thereby indirectly causing a reduction in indirect emissions. Moreover, traffic data can be potentially employed to the benefit of personal security, thus contributing to the safety sustainability aspect. For instance, it can provide support to decisions towards building safer bus stops along dangerous roads (e.g., due to high congestion or high driving speeds).

Collection of air quality data. Air pollution monitoring provide information that might be used to identify the need for more environmentally friendly transport services, for example, using public transport vehicles that produce less emissions. It may also support decisions regarding the introduction of public transport services that travelers might prefer over private car transport in areas with bad air quality.

Collection of transfer point data. Timetables optimization can be supported by retrieving detailed information about transfer points between services, so as to make travelers utilize routes involving multiple public transport services in a better way than they currently do. Among others, relevant transfer point data can be data about people's movements collected by different types of sensors.

Better-connected transport services may reduce the overall travel time, thus leading to better economical sustainability from the travelers' perspective. Improved timetables can also allow for transfer point data to be used to support sustainability by reducing the emissions from non-public transport, due to the fact that public transport services would become more attractive.

Transfer points might be used to the advantage of elderly and weak traveler groups, by adapting transfer points to their needs, thereby improving accessibility.

Use online services for modeling. An opportunity to develop analysis and problem solving models using data in an innovative way is represented by the use of online services to access the data collected by IoT devices and smartphones (such as crowdsourcing systems), and different types of processed data [49]. For instance, online services might be used by transport simulation models for analysis of public transport in order to access, e.g., weather data and current travel times, collected by different types of IoT sensors. Travel planner systems are a most relevant type of online service. They are mainly smartphone applications, are becoming increasingly popular, and it can be reasonably assumed that the travelers' decisions are changing on the basis of the suggestions provided by such systems. The use of travel planners might hence be leveraged to estimate people's travel behavior to increase the accuracy of the travel behavior modeling in simulation systems. Online services has the potential to affect all the sustainability aspects previously discussed, and thus support transport planning, even if indirectly, through leveraging the output from a variety of different models.

Real-time delay information. The traveler is able to make informed decisions on which transport service to select during a disturbance on the basis of information about the context, and delayed or cancelled transport services. Support to such decisions can be personalized through the use of information about the current location of the traveler (e.g., the bus they are on). Thereby, alternative travel routes can be suggested to the traveler. Hence, the real-time delay information supports the travel time sustainability aspect by helping the travelers to reach their destinations with minimum delay during disturbance. Eventually, improved real-time delay information might also support the reduction of indirect emissions by offering transport services that are more predictable, and therefore more attractive. Moreover, travelers with specific needs (e.g., elderly or disabled) can receive customized real-time information about transport alternatives with high accessibility. IoT technology can also provide information on delays (e.g., by devices capable of detecting bus stopping at the bus stop).

Co-traveler information. The IoT beacon technology could be used to provide information about which passengers are travelling on the same vehicle. Together with information about the passengers' destinations, such information can be leveraged to connect people, thus allowing for taxis sharing services during disturbances, or to reach the final destination in case using a bus or train is not a viable option. IoT-enabled improvements to co-traveler information is expected to also lead to improved sustainability, as it would improve resource utilization and indirectly reduce travel time. It is here assumed that taxis sharing services bring about indirect savings in terms of resources and emissions reduction in the transport system. Indirect emissions are also expected to decrease with the increase in attractiveness of the transport services, enabled by providing the users with easier ways to connect with one another. Furthermore, also this type of service might be valuable in case of disturbances.

Real-time vehicle information. Real-time information about the status and characteristics of the public transport vehicles can support the decision-making process about which public transport service to choose. First, travelers can use information about the number of passengers on a vehicle to identify overcrowded vehicles [50], thus giving them the possibility to making an informed decision on whether to travel by bicycle or wait for an overcrowded bus. Second, people with special needs (e.g., elderly, disabled) can be informed about relevant transport alternatives with real-time information about the characteristics and status of specific vehicles. Through the use of IoT, this type of information can be directed to passengers on board and/or to people waiting for a vehicle. The use of such information could serve several purposes:

informing a traveler if wheelchairs or baby strollers can be accommodated with ease on a bus, or whether bicycles are allowed on a specific train waiting on a track. Accessibility is, clearly, significantly affected by this type of information, which also makes the use of public transport more attractive. In addition, travelers could choose not to take a vehicle which does not have enough available room, and, hence, to reach their final destinations faster than without this information.

Delay compensation. Proving their presence on a delayed vehicle would allow travelers to more easily obtain price compensation for delays. IoT could make this possible by providing data about the context. It is expected that delay compensation will eventually contribute reducing indirect emissions, as getting a compensation could lead to opt for public transport despite the possible delays, whose associated risk is often high.

Interchange guidance. Providing context-aware information during interchanges could serve as a guidance to the traveler, allowing them, for instance, to reach the correct train platform or ticket office, and to help calculating the time required to reach it. Personal disability constraints might also be considered (e.g., need for wheelchair). Consequently, accessibility aspect of sustainability could be significantly affected by interchange guidance information; also, the interchange guidance might also result, even if indirectly, in travel time reduction in case the times for (planned) interchange are reduced as a consequence.

Ticket-buying support. Travelers may interact with ticketing and payment systems, which can be supported by IoT technology. IoT can be employed for ticket-buying support to provide positioning information to make ticket purchasing easier. In addition, ticket validity could be automatically extended in the event of disturbances. Obviously, ease-of-use and efficiency of ticketing systems contribute to the overall attractiveness of the public transport system. Furthermore, purchasing time could be reduced, thus leading to decreased travel times when correctly implemented; it would also may make it easier for travelers with special needs (e.g., children, intellectually disabled) to use public transport.

Support during travel. Travelers may benefit from support during travel, which would ensure that they are acting as planned. For instance, IoT-enabled support during travel might provide confirmation that the boarded vehicle is the correct one for the purpose of reaching the traveler’s destination, or tell if the traveler’s ticket is still valid, or give information about when to get off the vehicle. The public transport system could become more attractive and potentially also more accessible to larger groups of people (by appealing to, for instance, disabled people) through the use of such support. Moreover, travel times may indirectly be reduced by ensuring the traveler get off at the correct location along the route.

Enriched travel experience. Public transport can be made more attractive also by providing different types of data capable to enrich the travelling experience, such as, but not limited to contextual information about the current surroundings or the destination, or vehicle data that help travelers to keep track of the environmental impact caused by their travel (possibly comparing the impact to that caused by alternative modes of transport, e.g. private car).

8.2. Operations

Operations is a term that refers to public transport resource management. In particular, actions and decisions which are not taken into account in transport planning will constitute the main subject of this section. Consequently, the focus will be solely on the real-time aspects of operations. The data collected and generated by IoT systems not only bring about new opportunities, but can support the process of decision-making regarding resource use and services improvement. Usually, public transport services are timetabled. This makes of real-time information provided by IoT systems a useful means to handle disturbances, that is, deviations from the original plan. The main objective in such cases is to re-plan so as to restore the original conditions of the transport system according to the original plan (e.g., by getting stranded travelers to their destinations [41]. Regarding this topic, a more detailed overview of the existing literature can be found on [42].

Re-planning decisions can benefit from real-time data by enabling the planners to rely on more data and/or more accurate data. Taken actions are more easily communicated to both travelers and operators. Nevertheless, re-planning does not always have positive effects on sustainability, but better results can be obtained by accessing accurate, up-to-date information. In fact, public transport may be the cause of an increase in total emissions if, for instance, only few passengers are on-board.

8.2.1. Examples of opportunities

Improved management of operations. Knowledge on vehicles and travelers, as well as the vehicles that travellers will use and the route which they will select (e.g., through ticketing data, or sensor data, or information directly obtained from the traveler) can lead to improvements in operations management. Improved management can result especially useful in case of unplanned situations. As an example, the number of replacement vehicles (e.g. buses, taxis) could be more accurately decided in case of a train departure cancellation the occurrence of which requires to find alternative vehicles. Re-allocation or re-scheduling of other vehicles might also require an improved decision-making process. Having access to high quality information could lead to better decisions on decisions concerning whether a bus or train should wait for another delayed vehicle. For example, having even partial information on the number of passengers which will get on the waiting bus or train or knowing the expected waiting time could be fundamental.

Demand Responsive Transport (DRT). A vehicle in a DRT is shared among passengers who decide where it stops to pick up or drop off users [43]. The original goal behind DRT was to help disabled or elderly people, but nowadays can be regarded as a viable means to increase access and flexibility in public transport for the whole community. Bus routes acquire dynamicity and flexibility as they can be decided by the passengers. The only bus stops to be visited could be only those where the travelers want to exit and those where people are actually waiting. This would ensure more sustainability due to improved coverage and higher accessibility. The public transport alternatives enabled by DRT could, in the long run, lead to a reduction in indirect emissions, this being be the consequence of a more attractive and adaptive service capable of acquiring more users. Emissions could be potentially reduced by appropriately implementing the service in such a manner as to allow buses to take shortcuts, hence avoiding stops without awaiting users, or to employ smaller and fuel-efficient buses when demand is expected to be low. The implementation could also consider advising passengers to reach the closest bus stops to minimize their waiting time or to catch a fast transport service.

Maintenance-wear. More accurate decisions can be made by using status data provided by sensors. This would allow for fast recognition of immediate maintenance needs, hereby leading to less scheduling for maintenance and repair stops, and possibly even less maintenance time in total. Resources could be better exploited, adding to increased sustainability. Even if indirectly, also other aspects of sustainability such as safety and travel time, might be supported. Improved vehicles' maintenance might result in higher safety (e.g., less frequent brakes failure, no more worn out tires), which could also benefit from the avoidance of dangerous passengers evacuations (e.g., at congested roads). Fewer unscheduled stops are expected to lead to the avoidance of unnecessary waiting time. Better maintenance on vehicles might result in an additional reduction in waiting time for other vehicles sharing the same infrastructure, due to the fact that ill-maintained vehicles would not cause any damage to the infrastructure.

Maintenance-damage. Related to maintenance due to wear and tear, IoT could also be used to collect information about damage on the vehicles and the infrastructure used in public transport. Travelers, for instance, could submit reports on malfunctions contextualized by using data collected from the vehicles (e.g., broken seats or broken seat belts). This could increase the traveler's satisfaction in case that the response is immediate. Crowdsourcing enabling operators (in addition to other travelers) to take quick actions could be a potential application, as reported in [44]. Sustainability could benefit from this types of systems, as they will bring about reduced indirect emissions and make public transport services more attractive; also, this would ensure increased safety by swiftly identifying and repairing safety critical equipment.

Self-driving vehicles. IoT enables the development of self-driving vehicles, which significantly affect transport systems [45]. Transport overall cost and safety will be reduced by replacing human drivers. It will be possible to effectively prioritize improved driving patterns (e.g., eco-driving), hence leading to reduced emissions. Self-driving cars can be easily time-shared, which is another interesting opportunity. This is due to the fact that the re-allocation to the next user does not involve other human drivers. For example, a self-driving car can be rent for the weekends by one user and it may also be employed by public transport (e.g., as taxi) during the weekdays, hereby not requiring the user to care about the reallocation every week. To conclude, sustainability can be achieved also by benefiting from the use of self-driving cars, as they allow for reduced emissions and improved resource utilization; in addition, improvements in terms of safety can also be obtained, depending on the implementation.

Transport related services. IoT not only benefits traditional public transport operators through enabling innovative services and better decision making, but might also create opportunities for transport-related services. For instance, for taxi companies and bike renters, reduced travel time can result from providing information which supports the efficient re-allocation of available taxis and bikes. Public transport can be made more attractive through bike rental which might, for instance, enable travelers to move from one bus stop to another, and terminals using rented bikes. Services might also be created that help travelers to find non-occupied taxis and bikes. For instance, Munich developed a successful project on replacement taxis [46]. As a whole, the improvements previously discussed may directly reduce travel time and make public services more attractive, thereby leading to higher sustainability through fewer indirect emissions.

8.3. Considerations for smart cities and smart lands

Innovation opportunities enabled by IoT technologies are often associated with a urban context, e.g. with the concept of *smartcity*. However, the final scope of this paper is to show if and how the quality of rural transport systems can be improved through the implementation of such emerging technologies: the fundamental question is:

“Does only a urban environment provide suitable conditions for the successful application of IoT technologies, or can we imagine a *smart* mobility system for a *smartland* too?”

We find here a new concept, that is emerging in the most recent discussions on territorial development, in particular in Italy: the concept of **smartland**, defined as “a smart, sustainable, inclusive territory, where widespread and shared policies can improve the attractiveness and competitiveness of the territory, with a particular attention to social cohesion, spreading awareness, creative growth, accessibility and freedom of movement, usability and quality of the environment, quality of life for all citizens“ (freely translated from [52] - Original statement: *“un territorio sostenibile, intelligente, inclusivo», nel quale politiche diffuse e condivise sono in grado di aumentare la competitività e attrattività del territorio con una attenzione particolare alla coesione sociale, alla diffusione della conoscenza, alla crescita creativa, all’accessibilità e alla libertà di movimento, alla fruibilità dell’ambiente […] e alla qualità del paesaggio e della vita dei cittadini”*).

We have tried to answer the above question by comparing the possible implementation of the different IoT solutions presented in this chapter, in the two different settings.
The result of this evaluation was that **the identified opportunities can have very positive impacts both in smartcities and in smartlands**: as a fact, even if we consider the different levels of population scattering, technological infrastructures, social maturity, economic opportunities, almost all solutions can be implemented in rural territories as well as in urban contexts. The following analytical charts confirm such evaluation.

Applications for Planners	Urban Context	Rural Context
Collection of traveler data	☺ (green)	☺ (green)
Collection of vehicle data	☺ (green)	☺ (green)
Collection of traffic data	☺ (green)	☺ (green)
Collection of air quality data	☺ (green)	☺ (green)
Collection of infrastructure data	☺ (yellow)	☺ (green)
Collection of transfer point data	☺ (green)	☺ (green)
Online services for modeling support	☺ (green)	☺ (green)

Figure 19 – Suitability of the IoT Applications for Planners in Smartcities and Smartlands

Applications for Travelers	Urban Context	Rural Context
Real-time service information	☺ (green)	☺ (green)
Co-traveler information	☺ (green)	☺ (green)
Real-time vehicle information	☺ (green)	☺ (green)
Low level service compensation	☺ (yellow)	☺ (green)
Traveler support (interchange guidance, ticket purchase, …)	☺ (green)	☺ (green)
Enriched travel experience	☺ (green)	☺ (green)

Figure 20 – Suitability of the IoT Applications for Travelers in Smartcities and Smartlands

Applications for Operators	Urban Context	Rural Context
Management of Operations	☺ (green)	☺ (green)
Demand Responsive Transport (DRT).	☺ (green)	☺ (green)
Maintenance—wear	☺ (green)	☺ (green)
Maintenance—damage	☺ (green)	☺ (green)
Self-driving vehicles	☺ (green)	☺ (green)
Transport related services	☺ (green)	☺ (green)

Figure 21 – Suitability of the IoT Applications for Operators in Smartcities and Smartlands

9. Challenges

In this section, challenges relevant to the IoT within public transport will be discussed, especially in relation to the following categories: business models, privacy and integrity issues, security, interoperability, scalability, usability, data collection, and deployment. In some cases the identified challenges could be, at least partially, overcome with useful technologies. Some examples of such technologies are given below. Nevertheless, there is not a single solution capable of completely eliminating any of the identified challenges in all possible situations. More specifically, the application of existing technologies to the reported challenges could be hindered by the involved actors' insufficient knowledge. The relevant previous work should be reviewed if the challenges listed below have to be addressed, especially in the area of ITS. In particular, a variety of different general ITS architectures, face different challenges and technological developments. Being the architectures on a relatively high abstraction level, they are technology-independent specifications on components and communications which, in turn, implies that some of the interoperability challenges discussed below may be tackled by one specific ITS architecture. A single "standard" ITS architecture does not exist; depending on their needs, different countries and regions have developed their own customized ITS architecture. To develop global solutions, this lack of a single standard ITS architecture must be handled.

Business Models. IoT can be fully leveraged only if, in addition to the public transport operator, also a variety of other different actors are involved, such as telecommunication operators, sensor data providers, data storage providers, end-user service providers, public authorities, and the travelers themselves. To develop and maintain the necessary infrastructure, large investments may be needed, appropriate management and storage for the collected data must be ensured, along with the necessary services and data APIs, etc. As is to be expected, the involved actors have to sustain significant costs to build and maintain IoT systems; such costs have to be covered for in a reasonable way, in particular because efficient IoT systems can be developed and deployed only by employing certain types of actors. Devising effective business models represents a major challenge, as they regulate the distribution of the revenues to cover for the costs of the involved actors. Not only business models regulate how revenues and costs are distributed, but they also provide services to the end users, companies and other organizations. In fact, companies provide the necessary services only if business opportunities are properly identified, but are also out of the scope of the transport operators and public authorities; companies need to get a return on their investments. It must be noted that the closer to the customer/user one is in the information chain, the easier it is to get paid.

Open data sources and platforms for public transport services do exist (cf. www.trafiklab.se). Nevertheless, generating returns on investments in commercial data collection represents a major challenge. Business models concerning large amounts of data, i.e., "big data", have been thoroughly discussed by Bulger et al.. Public transport operations are typically subject to strict regulations and procurement of governmental agencies, which sometimes leads to transport operators be forced to supply data. Continuity and quality are, however, a major issue, and initiatives of other pure commercial and third party actors usually require business models.

Privacy and Integrity Issues. While privacy is concerned with not sharing data about organizations and individuals, integrity is about protecting against unauthorized modification of data. Not sharing information about the travels of individuals is often among the objectives of privacy in the public transport context. Such information include the movement of individual travelers, which can be tracked by mobile phone operators or by using RFID tags in travel cards

(Origin-Destination matrices can be generated with these data). The activities of people and items are today constantly monitored and recorded through a variety of sensors. Moreover, end users themselves submit information about their activities. Ensuring privacy and integrity of monitored individuals is thus a major challenge. Travelers' trust can be obtained by ensuring that no personal information is used or distributed without explicit consent. Among the most relevant challenges are: securing stored and communicated data against unauthorized access (both regarding disclosure and altering of the collected data), for instance, by using cryptography and access control in different ways; anonymization of the collected data preserving the ability to to trace the activities of individuals (that may be necessary to make strong analyses possible, e.g., to enhance the public transport system).

Security. Many types of potential malicious actors (e.g., cyber-terrorists, hackers) may attack the information systems of public transport, for various reasons. In addition to such actors, also competitors could be a threat. For instance, public transport service providers which have business interests in sub-optimal operations could also attack the system. The state-of-the-art of security, and also privacy in IoT systems is covered by Sicari et al. [52], whose work could help understand how it is possible to tackle malicious actors.

Interoperability. In machine-to-machine contexts, such as IoT, interoperability is a matter of major concern, considering that sensors and other types of devices to a large extent communicate without the involvement of humans. Interoperability refers to the ability of systems to work together. The IoT is characterized by a plethora of heterogeneous connected devices which work together and are provided by different vendors which use different technologies, hence qualifying interoperability issues as some of the main challenges for a well-functioning, connected IoT infrastructure. Interoperability-related challenges include development and usage of standardized protocols and interfaces for communication and service provision, such as standard web service protocols, middleware development, and others.

Scalability. Scalability, in IoT, is the ability of a system to function with an increasing number of users, sensors, and devices which continuously collect and process large amounts data. As previously mentioned, "big data" refers to the efficient management and use of this data. In fact, when the amount of data is small storing and processing tasks are not always a complex; however, when the amount of data grows at a seriously fast pace, as happens with the roll-out of IoT, there are some major challenges deriving from storing and processing needs which are related to the scalability, including storing all the collected data so as to preserve privacy and integrity, and analyzing and processing all the collected data to convert them into meaningful information, which can then be of use for a variety of actors (e.g., travelers and transport operators). Sometimes, data can not be stored as the amount of collected data is simply too much for it to be stored. Even if the data can be stored, there are cases in which privacy and integrity issues might prohibit the storage of sensitive data. Another challenge is real-time analysis of the data. Moreover, the huge amount of collected data (that maybe might not even be possibly stored) makes it extremely complex to properly aggregate data to make it usable for future analysis (e.g., for research purposes). Statistical distributions, for instance, can be a meaningful way to store data. Also, more efficient algorithms and models are needed to analyse the collected data and to solve problems (e.g., using simulation and mathematical optimization). Efficient heuristics are also needed that can be used to solve optimization problems (often in real time), due to the high complexity of many such problems.

Usability. Usability, in the IoT context, and especially when evaluated from the perspective of public transport sustainability, measures how easy it is for the involved actors to leverage the provided information and services (such as data collection and generation, e.g., via crowdsourcing). For example, travelers typically use smartphone applications or websites to access public transport planners. Thereby, mobile apps and websites are required to be user-friendly, making of high usability a prerequisite for achieving the benefits of IoT and particularly relevant to establish a connection with the travelers.

Data Collection. Sustainable development in the public transport context could be significantly supported by IoT thanks to the multiple possibilities enabled by data collection. Several challenges are, however, to be encountered in the actual collection of data. First, it is not an easy task that of determining what type of data can be collected, both in real-time and in retrospect. It is necessary to understand what type of data is actually useful and to which actors in a variety of different situations. Data collection and storage have to be performed in the best and most efficient way, which may include non-traditional methods, including crowdsourcing and the use of social networks (e.g., Twitter). Moreover, ways to ensure acceptable quality of collected data must be specified. Data can also be incorrect due to different reasons (e.g., poor quality IoT sensors, sensor spoofing or tampering from external individuals). For all these reasons, appropriate strategies which can be used to identify errors and inconsistencies in the collected data must be employed.

The challenges identified above can differently impact on a rural or in a urban environment. In this case, the differences are more relevant than those found in the previous chapter, concerning the suitability of the IoT technologies.

The following chart refers the different levels of difficulties generated by the challenges listed above

Issues	Urban Context	Rural Context
Sustainability of the Business Model		
Data Privacy and Integrity		
Security		
Interoperability		
Scalability		
Usability/Accessibility		
Data Collection		

Figure 22 – Suitablitity of the IoT Applications for Planners in Smartcities and Smartlands

10. UE Regulatory Framework

The European Commission is working to improve citizens' quality of life and strengthen the economy by promoting sustainable urban mobility and increasing use of clean and energy efficient vehicles. New political challenges have emerged in recent years. climate change, energy policy, air quality legislation and the difficulties of tackling congestion are just some examples. The objective now is the enhancement of sustainable mobility while at the same time the reduction of congestion, accidents and pollution in European cities.

Exchanging data between different actors in the transport system means supply and demand can be matched in real time, leading to a more efficient use of resources, be it a shared car, a container or a rail network. Digital technologies help to reduce human error, by far the greatest source of accidents in transport. They can also create a truly multimodal transport system integrating all modes of transport into one mobility service, allowing people and cargo to travel smoothly from door to door.

The Treaty of the Functioning of the European Union (TFEU)[1] is especially encouraging the sustainable mobility for specific target groups, such as workers (art. 202) by increasing their geographical and occupational mobility thanks to the European Social Fund (art.162), students and teachers, young people and their instructors (art.165) or researchers (art.180). Mobility on European soil has been implemented through the European Transport Policy, adopting rules for transport of both passengers and freight. This policy aims at "*completing the internal market, ensuring sustainable development [and] extending transport networks throughout Europe*" (articles 90 and 100 of the Treaty on the Functioning of the EU). Since 2001, the EU has encouraged more sustainable transport and multimodality.

In several European documents and guidelines the need for a technological evolution to optimize the transport system is pointed out[2], from the point of view of environmental sustainability, leading the European Commission to update legislation and standards on the involvement of many actors (Member States, regions, private subjects, etc.) in the European context and starting from the White Paper (2011) and its updating (2016).

COM (2011) 144: **WHITE PAPER, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system.**

Link: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN

This strategic document presents the ideas of the European Commission on the future of the European Union's transport system (EU) and defines a political agenda until year 2020. An efficient transport system, is an indispensable requirement to maintain the prosperity of the EU: there is a need for less traffic congestion, a reduction in emissions, an increase in employment and increased growth. Within the document, the guidelines are outlined in 10 points, pointing the application of new technologies, communication between the user and the

[1] The Treaty on the Functioning of the European Union (2007) is one of two primary Treaties of the European Union, alongside the Treaty on European Union (TEU). Originating as the Treaty of Rome, the TFEU forms the detailed basis of EU law, by setting out the scope of the EU's authority to legislate and the principles of law in those areas where EU law operates.

[2] From: "Policy guidelines for sustainable mobility in rural and mountain areas", Move on Green project, http://www.euromontana.org/wp-content/uploads/2014/06/Policy_Guidelines_Final_with_layout.pdf

vehicle and/or the vehicles and infrastructures, reducing emissions of pollutants and a "network" logic among the various modes of transport.

This White Paper, in particular, aims at the creation of framework conditions to promote the development and use of intelligent systems, which can be implemented through interoperable and multimodal scheduling, real-time passenger/travel information, online reservation systems and smart ticketing, traffic management for improved use of infrastructure and vehicles, as well as, promotion of awareness of the availability of alternatives to individual conventional transport (drive less, walk and cycle, car sharing, park & drive, intelligent ticketing etc.).

SWD[3] (2016) 226: **The implementation of the 2011 White Paper on Transport "Roadmap to a Single European Transport Area - towards a competitive and resource-efficient transport system"**.

Link: https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2011_white_paper/swd%282016%29226.pdf

This report looks at progress in the implementation of the initiatives under the ten-year programme of the 2011 Transport White Paper by the stock taking of the activities undertaken so far. One of the document annexes deepens the theme regarding the trends and developments of relevance for transport in the collaborative economy. Specifically it is about applying IT technologies for sustainable urban mobility (car sharing).

COM (2016) 766: **A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility**.

Link: https://ec.europa.eu/transport/sites/transport/files/com20160766_en.pdf

This document is the result of an intensive work with experts from both public and private sectors with the aim of identifying the issues and solutions for the application of the Cooperative Intelligent Transport System C-ITS platform in Europe in the transport sector. The Cooperative Intelligent Transport System represents an approach that, through the use of ITS, allows interaction between vehicles and between vehicles and infrastructure. The document explains the issues that should be tackled at EU level to ensure coordinated of C-ITS services by 2019. Specific actions to address each issue are proposed, including the enabling conditions at European, Member State, public authority and industry level.

COM (2016) 356: **A European Agenda for the Collaborative Economy**.

Link: https://ec.europa.eu/docsroom/documents/16881/attachments/2/translations/en/renditions/pdf

The document represents the first official position paper on Sharing Economy, issued by the Commission in the form of Communication. The Commission recognises the highly innovative potential of the collaborative platforms, because they enable new business models and create new opportunities for consumers and entrepreneurs. Also the transport market has already seen

[3] Staff Working Document

the raising of new services and initiatives inspired by the principles of this new paradigm. The Commission hopes that Europe is open to embracing these new opportunities to modernise the economy, even if the actual criticalities concerning fair competition, working conditions, adequate and sustainable consumer and social protection shall be solved by the Member States.

SWD (2016) 110: **Digitizing European Industry Reaping the full benefits of a Digital Single Market**.

Link: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016SC0110&from=EN

This Staff Working Document (SWD), which is built on a series of studies organized over the past 4 years, is part of the DSM (Digital Single Market) technologies and public services modernization package. It accompanies the Communication "Digitizing European Industry – Reaping the full benefits of a Digital Single Market" (in short Digitization Communication). In this domain, the concept of IoT is in depth described with its definition and specification of architecture and, in conclusion, there is the description of the application fields in which to adopt the IoT "logic" (e.g., Personal Wellness and Wearables, Smart Manufacturing, Smart cities, Smart energy, Automated Driving/Smart Mobility).

EU (2014): Connecting Europe's citizens and businesses.

Link: https://europa.eu/european-union/file/1232/download_en?token=xCql9RmY

This publication is a part of a document set that explains what the EU does in different policy areas, why the EU is involved and what the results are. This paper provides an overview of the evolution of the transport system policy within the European context. The European goal, as defined in the White Paper, is to reduce emissions and to incorporate the "network" logic in transport systems. The paper analyses how the policy has evolved in order to meet this need, from the point of view of infrastructure, but above all from the point of view of technological innovation applied to the transport world.

EU (2016): Towards a Strategic Transport Research and Innovation Agenda (STRIA)

Link: http://ec.europa.eu/programmes/horizon2020/en/news/towards-strategic-transport-research-innovation-agenda-stria

The document is a report regarding the transport stakeholders' involvement in which a strategic program for research and innovation in transport (STRIA) has been defined. Some issues have been addressed in the context of transforming and decarbonising the EU transport system such as: Electrification, Alternative, Fuel, Vehicle Design and Manufacturing, Connected and Automated Transport, Transport Infrastructure, Network and Traffic Management Systems, Intelligent Transport and urban mobility services).

Move on Green project[4]

Move on Green, project co-financed by the European Regional Development Fund and by the Interreg IV C programme, aimed to maintain the environmental and economic health of rural areas and to ensure the access of both inhabitants and potential visitors to key services such as employment, education and healthcare.

To do so, Move on Green had the objective to improve the design and effectiveness of regional policies on sustainable transport in rural and mountain areas.

To achieve these goals, during 3 years, 13 partners from 10 EU countries have collected examples of innovative ground-level initiatives and prepared a Good Practice guide on innovative transport solutions to help decision makers to get inspiration and improve their transport patterns. Partners have then derived from this practical experience these Policy Guidelines on Sustainable Transport in rural areas to foster policy-learning for European and regional policy-makers.

Finally, each regional partner has prepared an Implementation plan to concretely adapt its policy towards more sustainable mobility schemes and transfer new sustainable transport practices at regional and local levels.

At the end of the project, several Good Practices were successful transferred within the partners' regions and transport policies have sometimes even been changed.

The project demonstrated these Policy Guidelines can be of great help for all policy-maker to encourage them to adapt their transport policy to the specific characteristics of rural and mountain areas, to be inspired by Move on Green good practices and transferred them into their own areas to improve sustainable mobility.

Conclusions

Starting from 2011 there has been a development from a regulatory perspective to achieving the efficiency of the transport service. The concept of environmental sustainability of transport services is realized through the technological innovation of vehicles and infrastructures.

As of January 2014, the EU has a new transport infrastructure policy that will connect the continent from east to west, north to south. This policy aims to close the gaps between national transport networks, remove bottlenecks that still hamper the smooth functioning of the single market and overcome technical barriers such as incompatible standards for rail traffic.

In order to concretise the development plans, the policy will also benefit from the Commission's 3-year investment plan, funded through the Connecting Europe Facility, with a budget of €26bn up to 2020 and designed to unlock public and private investment of at least €315bn by 2017[5].

[4] From: "Policy guidelines for sustainable mobility in rural and mountain areas", Move on Green project, http://www.euromontana.org/wp-content/uploads/2014/06/Policy_Guidelines_Final_with_layout.pdf

[5] Source: https://europa.eu/european-union/topics/transport_en

References

[1] Nokia, An Internet of Things blueprint for a smarter world, Strategic White Paper, 2016. https://resources.alcatel-lucent.com/asset/190140

[2] Behmann F., Wu K., Collaborative Internet of Things (C-IoT): for Future Smart Connected Life and Business, Wiley, 2015.

[3] Gubbia J., Buyyab R., Marusic S., Palaniswami M., Internet of Things (IoT): A vision, architectural elements, and future directions. In: Future Generation Computer Systems, 2013, Vol. 29, pp. 1645–1660.

[4] Ashton K., That ‘‘Internet of Things’’ thing, RFiD Journal (2009).

[5] Sundmaeker H., Guillemin P., Friess P., Woelfflé S., Vision and challenges for realising the Internet of Things. In: Cluster of European Research Projects on the Internet of Things—CERP IoT, 2010.

[6] Buckley J. (Ed.), The Internet of Things: From RFID to the Next-Generation Pervasive Networked Systems, Auerbach Publications, New York, 2006.

[7] Akyildiz I. F., Su W., Sankarasubramaniam Y., Cayirci E., Wireless sensor networks: a survey, Computer Networks, 2002, Vol. 38, pp. 393–422.

[8] Weiser M., Gold R., The origins of ubiquitous computing research at PARC in the late 1980s, IBM Systems Journal, 1999.

[9] Caceres R., Friday A., Ubicomp systems at 20: progress, opportunities, and challenges, IEEE Pervasive Computing, 2012, Vol. 11, pp. 14–21.

[10] Atzori L., Iera A., Morabito G., The Internet of Things: a survey. In: Computer Networks, 2010, Vol. 54, pp. 2787–2805.

[11] Sundmaeker H., Guillemin P., Friess P., Woelfflé S., Vision and challenges for realising the Internet of Things. In: Cluster of European Research Projects on the Internet of Things-CERP IoT, 2010.

[12] Belissent J., Getting clever about smart cities: new opportunities require new business models, Forrester Research, 2010.

[13] Talari S., Shafie-khah M., Siano P., Loia V., Tommasetti A., Catalão J. P. S., A Review of Smart Cities Based on the Internet of Things Concept. In: Energies, MDPI, 2017.

[14] Jaradat M., Jarrah M., Bousselham A., Jararweh Y., Al-Ayyoub M., The Internet of Energy: Smart Sensor Networks and Big Data Management for Smart Grid. In: Procedia Computer Science, 2015, Vol. 56, pp. 592-597.

[15] Whitmore A., Agarwal A., Da Xu L., The Internet of Things—A survey of topics and trends. In: Information Systems Frontiers, 2015, Vol. 17, Issue 2, pp. 261–274.

[16] Ngai E. W. T., Moon K. K. L., Riggins F. J., Yi C. Y., RFID research: an academic literature review (1995–2005) and future research directions. In: International Journal of Production Economics, 2008, Vol. 112, Issue 2, pp. 510–520.

[17] Zhu C.; Leung V. C. M.; Shu L.; Ngai E. C. H., Green Internet of Things for Smart World. In: IEEE Access 2015, Vol. 3, pp. 2151–2162.

[18] Rawat P., Singh K. D., Chaouchi H., Bonnin J. M., Wireless sensor networks: A survey on recent

developments and potential synergies. In: J. Supercomput. 2014, Vol. 68, pp. 1–48.

[19] Hancke G., Silva B., Hancke G. Jr., The Role of Advanced Sensing in Smart Cities. In: Sensors 2012, Vol. 13, pp. 393–425.

[20] Zanella A., Bui N., Castellani A., Vangelista L., Zorzi M., Internet of Things for Smart Cities. In: IEEE Internet Things J., 2014, Vol. 1, pp. 22-32.

[21] Medagliani P., Leguay J., Duda A., Rousseau F., Duquennoy S., Raza S., Ferrari G., Gonizzi P., Cirani S., Veltri L., Monton M., Domingo M., Dohler M., Villajosana I., Dupont O., Internet of Things Applications-From Research and Innovation to Market Deployment. In: Bringing IP to Low-Power Smart Objects: The Smart Parking Case in the CALIPSO Project; The River Publisher, Series in Communication: Delft, The Netherlands, 2014, pp. 287–313.

[22] Pike J., The Internet Of Things And Machine Learning, Moor Insights and Strategy, 2016. https://www.forbes.com/sites/moorinsights/2016/03/16/the-internet-of-things-and-machine-learning/#5b7022123fb1

[23] Haiyan L., Song C., Dalei W., Stergiou N., Ka-Chun S., A remote markerless human gait tracking for e-healthcare based on content-aware wireless multimedia communications, IEEE Wireless Communications, 2010, Vol. 17, pp. 44-50.

[24] Nussbaum G., People with disabilities: assistive homes and environments, in: Computers Helping People with Special Needs, 2006.

[25] Yun M., Yuxin B., Research on the architecture and key technology of Internet of Things (IoT) applied on smart grid. In: Advances in Energy Engineering, ICAEE, 2010, pp. 69–72.

[26] Kumar P., Ranganath S., Huang W., Sengupta K., Framework for real-time behavior interpretation from traffic video. In: IEEE Transactions on Intelligent Transportation Systems, 2005, Vol. 6, pp. 43–53.

[27] Lin H., Zito R., Taylor M., A review of travel-time prediction in transport and logistics. In: Proceedings of the Eastern Asia Society for Transportation Studies, 2005, Vol. 5, pp. 1433-1448.

[28] Mayer-Schönberger V., Failing to forget the ‘‘Drunken Pirate’’. In: Delete: the Virtue of Forgetting in the Digital Age (New in Paper), first ed., Princeton University Press, 2011, pp. 3-15.

[29] Methodology and indicator calculation method for sustainable urban mobility. World Business Council for Sustainable Development. Project 2.0 (SMP2.0), WBCSD, 2015.

[30] Olaverri-Monreal C., Autonomous Vehicles and Smart Mobility Related Technologies. In: Infocommunications Journal, 2016, Vol 8, pp. 17-24.

[31] Filgueiras J., Rossetti R. J., Kokkinogenis Z., Ferreira M., Olaverri-Monreal C., Paiva M., Tavares J. M. R., Gabriel J., Sensing bluetooth mobility data: potentials and applications. In: Computer-based Modelling and Optimization in Transportation. Springer, 2014, pp. 419-431.

[32] Olaverri-Monreal C., Gomes P., Fernandes R., Vieira F., Ferreira M., The See-Through System: A VANET-enabled assistant for overtaking maneuvers. In: Intelligent Vehicles Symposium (IV). IEEE, 2010, pp. 123–128.

[33] Gomes P., Olaverri-Monreal C., Ferreira M., Making vehicles transparent through v2v video streaming. In: IEEE Transactions on Intelligent Transportation Systems, 2012, Vol. 13, Issue 2, pp. 930–938.

[34] Carsten O., Fowkes M., Lai F., Chorlton K., Jamson S., Tate F., Simpkin B., ISA - UK, Final Report, 2008. http://webarchive.nationalarchives.gov.uk/20101007153833/http:/www.dft.gov.uk/pgr/roads/vehicles/intelligentspeedadaptation/fullreport.pdf

[35] Sadeghi-Bazargani H., Saadati M., Speed Management Strategies - A Systematic Review. In: Bulletin of Emergency and Trauma, 2016, Vol. 4, Issue 3, pp. 126-133.

[36] Van-Bao T., Verge M., Nazih M., Guichon D., Salim S., Development of a Dynamic Intelligent Speed Adaptation. In: Procedia - Social and Behavioral Sciences, 2012, Vol. 48, pp. 2111-2120.

[37] Kolosz B., Grant-Mulle, Extending cost–benefit analysis for the sustainability impact of inter-urban Intelligent Transport Systems. In: Environmental Impact Assessment, Elsevier, 2015, Review 50 (2015), pp. 167-177.

[38] Sarowar S. S., Shende S. M., Overspeed Vehicular Monitoring and Control by using ZigBee. In: International Journal of Current Engineering and Technology, 2015, Vol. 5, Issue 4, pp. 2349-2352.

[39] Zhao Y., Li S., Hu S., Su L., Yao S., Shao H., Wang X., Abdelzaher T., GreenDrive: A smartphone-based intelligent speed adaptation system with real-time traffic signal prediction. In: 8th ACM/IEEE International Conference on Cyber-Physical Systems, ICCPS 2017, Pittsburgh, United States, pp. 229.238.

[40] Davidsson P., Hajinasab B., Holmgren J., Jevinger Å, Persson J. A., The Fourth Wave of Digitalization and Public Transport: Opportunities and Challenges. In: Sustainability, MDPI, 2016, Vol. 8, Issue 12.

[41] Darmanin T., Lim C., Gan H., Public Railway Disruption Recovery Planning: A new recovery strategy for metro train Melbourne. In: Proceedings of the 11th Asia Pacific Industrial Engineering and Management Systems Conference, Melaka, Malaysia, 2010.

[42] Jespersen-Groth J., Potthoff D., Clausen J, Huisman D., Kroon L., Maróti G., Nielsen M.N., Disruption Management in Passenger Railway Transportation. In Robust and Online Large-Scale

Optimization, LNCS; Ahuja, R., Möhring, R., Zaroliagis, C., Eds.; Springer International Publishing: Berlin, Germany, 2009, Vol. 5868, pp. 399-421.

[43] Ronald N., Thompson R., Haasz J, Winter S., Determining the Viability of a Demand-Responsive Transport System under Varying Demand Scenarios. In: Proceedings of the 6th ACM SIGSPATIAL International Workshop on Computational Transportation Science, Orlando, FL, USA, 5–8 November 2013.

[44] Lau S. L., Ismail S. S., Towards a real-time public transport data framework using crowd-sourced passenger contributed data. In: Proceedings of the 82nd IEEE Vehicular Technology Conference, Boston, MA, USA, 6–9 September 2015.

[45] Brownell C., Kornhauser A. A, Driverless Alternative—Fleet Size and Cost Requirements for a Statewide Autonomous Taxi Network in New Jersey. In: Journal of the Transportation Research Board, 2014, Vol.2416, pp. 73–81.

[46] Zeng A. Z., Durach C. F., Fang Y., Collaboration decisions on disruption recovery service in urban public tram systems. In: Journal of the Transportation Research Board, 2012, Vol. 48, pp. 578–590.

[47] Xia H., Qiao Y., Jian J., Chang Y, Using smart phone sensors to detect transportation modes. In: Sensors, 2014, Vol. 14, pp. 20843–20865.

[48] Artikis A., Weidlich M., Schnitzler F., Boutsis I., Liebig T., Piatkowski N., Gal A., Mannor S., Kinane D., Gunopulos D., Heterogeneous Stream Processing and Crowdsourcing for Urban Traffic Management. In: Proceedings of the 17th International Conference on Extending Database Technology, Athens, Greece, 24–28 March 2014.

[49] Hajinasab B., Davidsson P., Holmgren J., Persson J. A., On the use of on-line services in transport simulation. In: Proceedings of the International Symposium of Transport Simulation, Jeju, Korea, 29 August–2 September 2016.

[50] Farkas K., Nagy A. Z., Tomás T., Szabó R., Participatory sensing based real-time public transport information service. In: Proceedings of the 2014 IEEE International Conference on Pervasive Computing and Communications Demonstrations, Budapest, Hungary, 24–28 March 2014.

[51] Sicari S., Rizzardi A., Grieco L. A., Coen-Porisini A., Security, Privacy and Trust in Internet of Things: The road ahead. Computer Networks, 2015, Vol. 76, pp. 146–164.

[52] Bonomi A., Masiero R., Dalla smart city alla smart land. Marsilio, 2015.