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D.1.2

Final Specification of IoT-enabled Autonomous Driving use cases

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Abstract

This document presents the final specification of use cases aimed to assess the potential of Internet of Things for enhancement and enabling of Automated Driving. A description of the use cases is provided for five European pilot sites and the Korean pilot site, each offering specific scenarios of interest. The potential of the Internet of Things to progress Automated Driving beyond the state of the art is explained by way of hypotheses on the impact of IoT on these use cases along with a set of performance indicators to evaluate them. The document is based on the experience gained during the realisation of the project, as well as from the piloting activities.

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
(C-)ITS	(Cooperative) Intelligent Transport Systems
ACC	Adaptive Cruise Control
AD	Automated Driving
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving System
AVP	Automated Valet Parking
BLE	Bluetooth Low Energy
BT	Bluetooth
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CeH	Connected Electronic Horizon
DDT	Dynamic Driving Task
DITCM	Dutch Integrated Testsite Cooperative Mobility
DENM	Decentralized Environmental Notification Message
DMAG	Data Modelling Activity Group in AUTOPILOT
ETSI	European Telecommunications Standards Institute
FCA	Fiat Chrysler Automobiles
GA	Grant Agreement
GPS	Global Positioning System
HMI	Human machine interface
ICAO	International Civil Aviation Organization
IoT	Internet of Things
ISI	Intersection Safety Information
ISS	Image Sensing System
ITS	Intelligent Transport Systems
LIDAR	Light Detection And Ranging
LDM	Local Dynamic Map
MAP	Map Data
NAHSC	National Automated Highway Systems Consortium
OBU	On-board Unit
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
PoI	Point of Interest
PS	Pilot Site
QoS	Quality of Service
RADAR	RAdio Detection And Ranging
RFID	Radio-Frequency Identification
RHW	Road Hazard Warning
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SAREF	Smart Appliances REFerence
SPat	Signal Phase and Timing
TLA	Traffic Light Assist
TCC	Traffic Control Centre
V2I/V2V/V2X	Vehicle to Infrastructure / Vehicle / Everything
VMS	Variable Message Sign

VRU	Vulnerable Road User (e.g. pedestrian, cyclist)
WEF	World Economic Forum
WM	World Model
WP	Work Package

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Executive Summary

AUTOPILOT concerns the use of Internet of Things (IoT) for enabling Automated Driving (AD). The extent and volume of information sources that can be addressed through IoT is seemingly unlimited, offering potential improvements of automated driving (including improvements in security, efficiency, accuracy, etc.) enabling the range of applications and services. In order to evaluate the potential and calculate the related impacts of using IoT for AD, a set of use cases were implemented at AUTOPILOT's six pilot sites.

Each Automated Driving use case includes vehicles driving in at least one automated driving mode and involves one or more services or applications in a specified environment. Pilot sites offer a variety of operational conditions for the use cases, thanks to the differences between the six sites and the stakeholders involved. An overview of AUTOPILOT's Automated Driving use cases in the various pilot sites is provided in Table 1.

Table 1: Overview of Automated Driving use cases in pilot sites.

Pilot sites	Use cases	Automated driving modes	Services	Applications
Finland Tampere	Urban Driving	Platooning	None	Driving Route optimisation
	Automated Valet Parking (AVP)	AVP	None	None
France Versailles	Urban driving with car sharing and city chauffeur services for tourists	Urban Driving	Car sharing and city chauffeur services for tourists	None
	Platooning for automated fleet rebalancing	Platooning AVP	Driverless car rebalancing	None
Italy Livorno	Highway Piloting	Highway Piloting	None	Dynamic eHorizon
	Urban driving	Urban driving	None	None
Netherlands Brainport	Platooning	Platooning	None	Driving Route optimisation
	Urban driving with driverless car rebalancing	Urban driving	Driverless car rebalancing	6th sense driving
	Highway Piloting	Highway Pilot	None	6th sense driving
	Automated Valet Parking	AVP	None	None
	Mobility Service	Platooning Automated Valet Parking	None	Digital driver license
Spain Vigo	Urban driving	Urban driving	None	None
	Automated Valet Parking	AVP	None	None
Korea Daejeon	Urban driving	Urban driving	None	None

This document specifies the Automated Driving use cases that the project comprehensively assesses. The assessment targets usage of IoT techniques in automated driving. The hypotheses on the expected impact of Internet of Things in these use cases and the key performance indicators to support the evaluation activities are also specified in this deliverable.

1 Introduction

1.1 Internet of Things (IoT)

The Internet of Things (IoT) represents a major economic and societal innovation wave enabled by the internet. The term "Internet of Things" was first coined by Kevin Ashton in 1999, while working on identification systems related to RFID and presented as slides to P&G (Procter and Gamble). A basic definition of IoT is: *a network that connects uniquely identifiable "Things" to the Internet*[1]. The *"Things" are* uniquely identifiable physical or virtual objects connected to other objects and to the Internet. The Internet enables data exchange between things as well as between humans and things. The Things could be basic objects such as sensors and actuators or higher object classes such as bikes and cars. They interact with other objects (object-classes) to exchange data such as temperature, load level, and speed to remote hosts such as manufacturers, operators or other connected devices to be remotely monitored or even controlled through Internet protocols. IoT thus extends Internet connectivity beyond traditional Personal Computers and Servers, to physical devices and everyday objects. IoT aims at combining the physical and the virtual worlds into a new smart environment, which senses, analyses and adapts, and which can make our lives easier, safer, more efficient and more user-friendly[2].

For a more comprehensive definition of IoT, it is important to consider the scope of IoT in a more generalised, and continuously evolving manner. In AUTOPILOT, IoT is mainly considered as a methodology for managing connected devices and their data. It encompasses the use of a common architecture identifying standardised interfaces in the cloud architecture, but also data models or even more - ontologies (i.e. SAREF). Mainly, the physical objects in the IoT are considered as their respective virtual representations, namely *digital twins*.

1.2 Purpose of the document

The purpose of this document is to provide the final specification of IoT-enabled Autonomous Driving use cases that are piloted in AUTOPILOT project. The first deliverable of Task T1.1, D1.1[3], submitted in M06, provided an initial specification of IoT-enabled Autonomous Driving use cases. It served as a baseline for further specification of other WP1 tasks such as IoT Architecture, IoT platforms, Communication, Security, Privacy and Data as well as the development, piloting and evaluation activities in work packages 2, 3 and 4, respectively.

D1.2 aims at updating the specifications based on the experience gained during the realization of the project, as well as from its piloting activities, especially from the technical and user acceptance tests (iterations) carried out in the project. General descriptions of the extensions enabled by IoT, hypotheses on IoT impact, performance evaluation (scenarios, KPIs and expected results) and various recommendations for carrying out activities in other work packages were included in D1.1. Since they have been addressed in the deliverables (D2.4, D3.2, D4.2) of work packages 2, 3 and 4, these descriptions are excluded from this deliverable. For completeness of the use case specification, the hypotheses that are tested and performance indicators that are validated in the project are included along with their description.

[1] IEEE IoT Towards Definition of Internet of Things - Revision1, 27-MAY-15

[2] https://ec.europa.eu/digital-single-market/en/internet-of-things, accessed on 31st July 2019.

[3] [AUTOPILOT] D.1.1 Initial Specification of IoT-enabled Autonomous Driving use cases

1.3 Intended audience

The dissemination level of this document is public and hence the targeted audience are all stakeholders interested in topics of the project. Internally, the document will be used as the base for updating Work Package 1 tasks T1.2, T1.3, T1.4 and T1.5, as well as for the technical evaluation (T4.2) in WP4.

1.4 Definitions

In this report, the following definitions are used:

Automated driving vehicle

A vehicle that has the capability to drive without human operation using on-board sensors, actuators, software and other information such as stored maps. The vehicle may also have connectivity to other vehicles, the infrastructure or the cloud to enhance its capabilities. In the economic context, the automated driving vehicle is a tangible, physical product.

Automated driving modes

The way in which automated driving is performed or experienced.

Service

A non-physical, intangible product providing customer value to users.

Application

Tools or software developed in other domains of the automotive industry (re)used to support AD functions.

Storyboard

A storyline describing how a service or services involving IoT-enabled (automated) vehicles evolves.

Scenario

Specific traffic situation that may be encountered by (automated) vehicles on the road.

Use case

A set of scenarios for automated driving, containing a description of goals, as a set of possible sequences of interactions between users, automated vehicles driving in an automated mode, and related services or applications in specific pilot site environments.

These definitions are used to distinguish between AD modes, services, applications and the corresponding use cases as shown in Figure 1. However, they may also have identical names. E.g. consider automated valet parking: An automated vehicle may have an automated valet parking driving mode and might be able to park itself only using its built-in software, sensors, actuators, etc. However, a parking garage may also offer automated valet parking by providing a service to the user of the automated car, in which for example a parking space is reserved, and a map and route to the reserved parking space is communicated. Hence, in an automated valet parking use case the interactions between users, automated driving vehicle and related valet parking services are investigated.

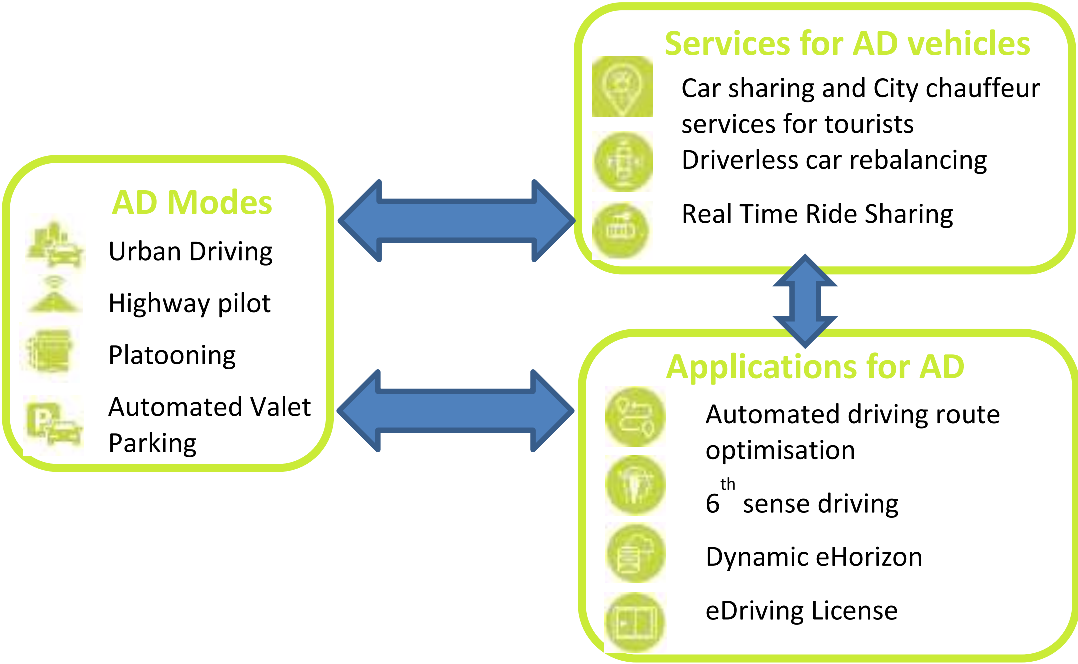

Figure 1: Autonomous Driving use cases and the interaction between AD modes, services and applications

SAE levels of automation

Society of Automotive Engineers (SAE) has defined six levels of automation which are summarized in Figure 2. A more detailed description of these levels and definition of the terms used are provided in Annex 5.1.

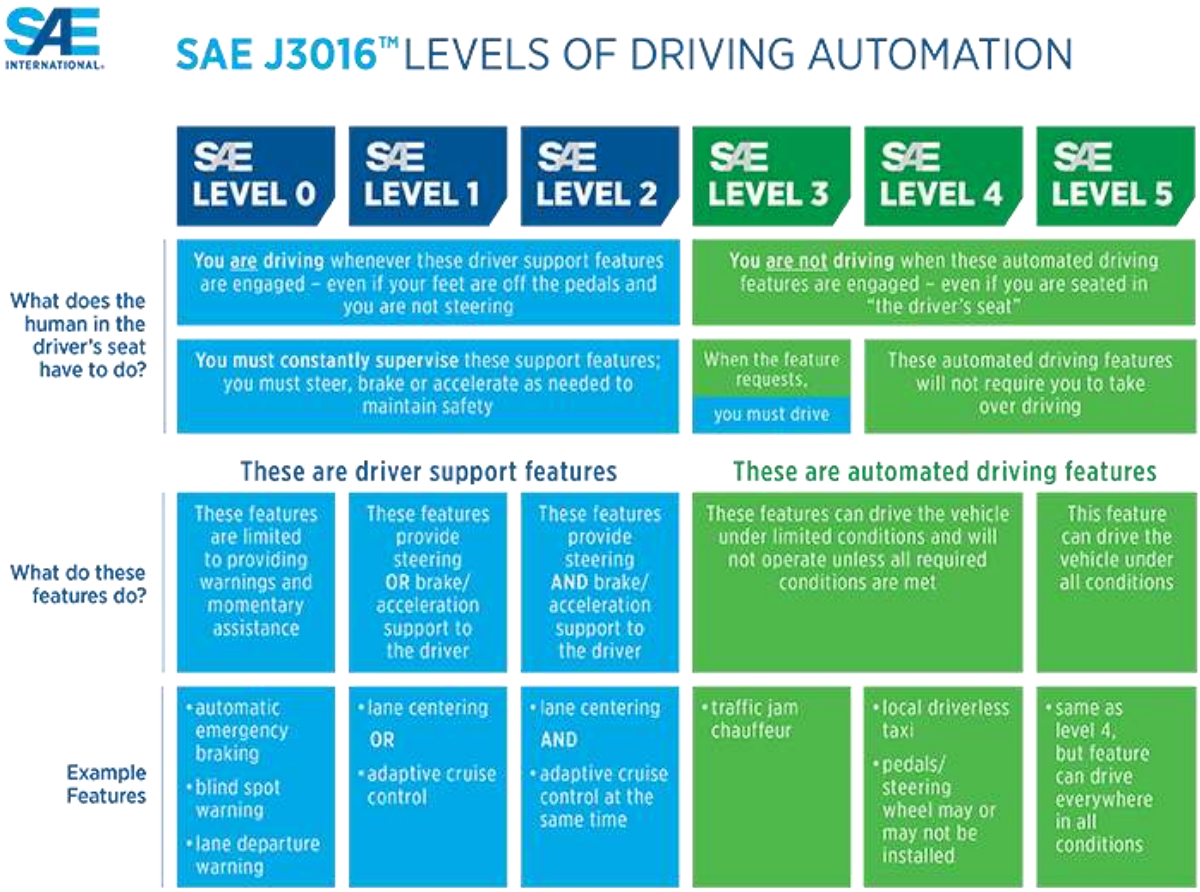

Figure 2: SAE J3016 levels of driving automation, as described in J3016

1.5 Process

The initial specification of IoT-enabled Autonomous Driving use cases followed a process that included several workshops, and intermediate progress meetings. At a general kick-off workshop, the pilot site leaders defined the outline of the use cases specification. Workshops were held at each pilot site with (mainly) local partners to result determine specification details with the use case teams (note that each pilot site has specific use cases). The descriptions were unified towards the creation of the contents of this deliverable in a consolidation workshop attended by use case leaders from all pilot sites. Initial key performance indicators were also derived, leading to the scenarios of interest for evaluation for each of the use cases. The process is schematically depicted in Figure 3.

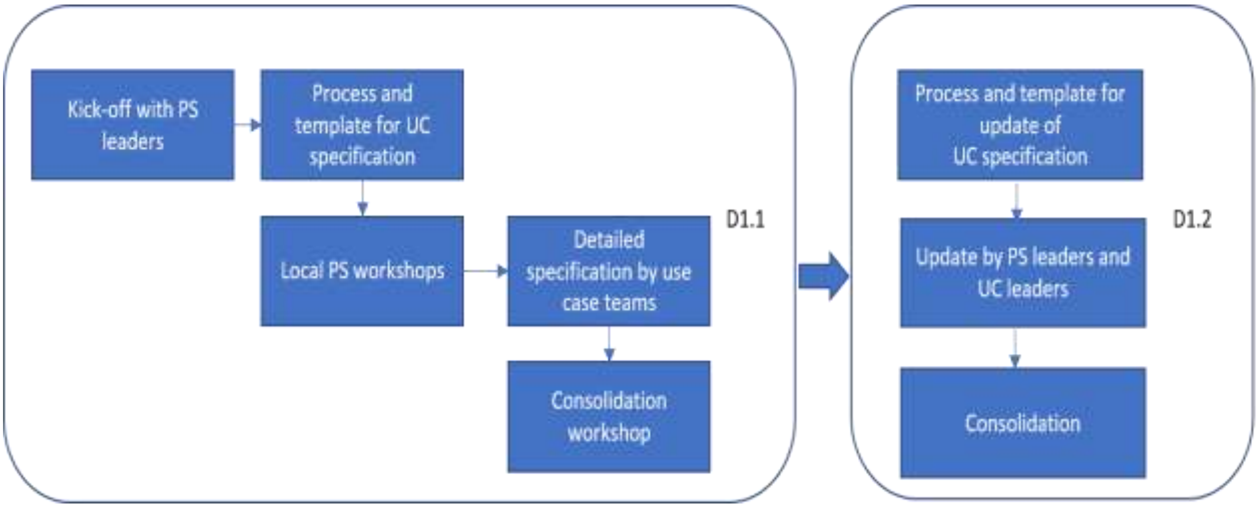

Figure 3: Process scheme.

In the final specification, the pilot site leaders, use case leaders, services and application providers updated the initial specification based on the knowledge gained from the implementation and piloting activities. An internal review process recommended restructuring of the document, which triggered a second round of updates and revisions by the pilot site leaders. The contributions were consolidated to produce the final version of the document.

1.6 Document Outline

The rest of the document is outlined as follows: Chapter 2 provides the specification of building blocks of the IoT-enabled Autonomous Driving use cases categorised according to AD modes, AD services and AD applications. Then, the specification of these use cases in various pilot sites is described in Chapter 3. It also specifies how Internet of Things could progress automated driving beyond the state of the art, the hypotheses on IoT impact and the suggested performance indicators for evaluation. Conclusions and summary of the specifications are given in Chapter 4. Additional description of SAE levels and definition of the terms are provided in Chapter (Annex) 5.

2 Specification of building blocks of IoT-enabled Autonomous Driving Use Cases

As explained in Section 1.4 and shown in Figure 1, an autonomous driving use case includes vehicles driving in at least one automated driving mode and interacts with one or more services or applications in a specified environment. In this section, the building blocks of the use cases, namely the automated driving modes, related services and applications are specified. It includes a functional description as well as the state-of-the-art.

2.1 Automated Driving Modes

2.1.1 Automated Valet Parking

2.1.1.1 Function Description

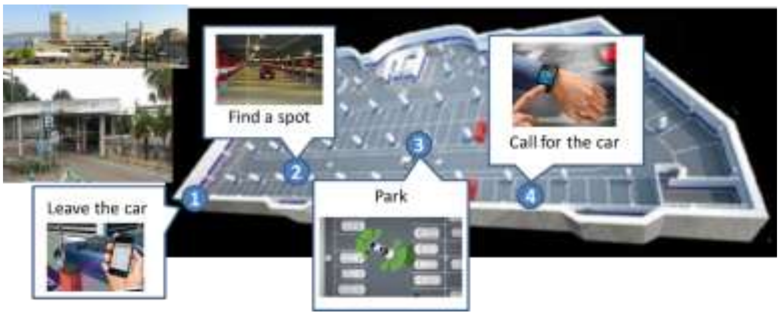

Figure 4: Automated Valet Parking Sequence.

The concept of *Valet Parking* is widely used all over the world; for example, the more luxurious hotels offer such a service. Once a customer arrives with his/her vehicle at the hotel, he/she gets out of the vehicle and hands over the car-keys to the hotel personnel, which will then drive the vehicle to its parking spot, relieving the customer from that task. In the meantime, the owner of the vehicle can e.g. check-in or attend a meeting. Likewise, the vehicle is returned by the hotel personnel upon the request of the relevant customer. Utilising the technology evolution of self-driving vehicles, it seems logical to also automate the valet parking concept, referred to as *Automated Valet Parking*, or AVP.

In AVP (see Figure 4), the vehicle will park itself after the driver has left the car at a *drop-off* point, which may be located near the entrance of a parking lot. When the driver wants to leave the site, he/she will simply request the vehicle to return itself to the *collect* point, using (for example) a smartphone app.

To navigate safely around the parking lot to its destination, the automated vehicle uses driving functions based on knowledge about the environment around the vehicle. An example would be a navigation functionality based on a digital map, positions of the automated vehicle and vacant parking spots. The vehicle can use its own functions and sensors to accomplish this task, but it can also benefit from accessing IoT platforms which can provide data and functions based on IoT enabled sensors like parking cameras. Furthermore, IoT platforms may provide information to support services for booking and payment.

The aim of AUTOPILOT is to demonstrate how the AVP functionality can benefit from such information sources, other than the on-board sensors, accessed via the Internet-of-Things.

2.1.1.2 State of the Art

Automated Valet Parking has been an active field of research for several years now. In the last decade, several car manufacturers have introduced automated parking systems. Most of those systems aid drivers to park the car near a selected parking spot. Systems in which a vehicle drives autonomously over a longer distance within a parking lot, however, are not yet available on the market.

AVP was demonstrated as early as 2007 as part of the DARPA Urban Challenge[4]. In 2010, the enterprise Valeo featured a concept video of automated valet parking dubbed ‘Park4U’[5]. In January 2013, Audi demonstrated valet parking dubbed ‘robot valet’ of a model A7 automobile in an underground setting during the CES 2013 event[6].

In 2013, Ford introduced *Fully Assisted Parking Aid*[7], which can automatically park the vehicle in an empty spot. The vehicle can steer, brake and throttle automatically and additionally the gearbox can be controlled (forward and drive). During the whole manoeuvre the driver must press and hold a button, either in the vehicle, or standing outside using a remote control. Volkswagen recently introduced *Trained Parking* in which a car can be "taught" to park into a parking place that is used routinely, such as at home or at work, and then can subsequently park into that spot without a driver present.

At the Intelligent Transportation Systems (ITS) World Congress in Tokyo in 2013, Honda demonstrated an AVP function, which uses cameras positioned around the parking lot[8]. According to Honda, the system can be fully operational around 2020. This concept requires no additional expensive sensors (cameras, radars, etc.…) on the vehicle other than those already in use for short-range parking aid. The downside of this is that it requires a fully equipped parking garage. Apart from OEMs, automotive suppliers are also active in the field of automated parking systems. Bosch, for instance, offers multiple parking solutions[9] such as home zone park assist.

In July 2013, the Renault organisation demonstrated automated valet parking (among other AV use-cases) as a first in France. The demonstrator public name was chosen to be ‘Next Two’ even though the codename of the earlier project was ‘Kairos’. The first AVP features of ‘Kairos’ were demonstrated as early as February 2013. The public video of January 2014 was widely broadcasted

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[4] M. Montemerlo, et.al., “Junior: The Stanford Entry in the Urban Challenge,” in Journal of

Field Robotics, vol. 25, no. 9, pp. 569–597, 2008.

[5] https://www.valeo.com/en/park4u-automated-parking/ accessed on 20th August 2019.

[6] https://youtu.be/hlvipzPWnE0 accessed on 20th August 2019.

[7] http://www.autoblog.com/2013/10/09/ford-fully-automated-self-parking-car-video/ accessed on 31st July 2019

[8] http://www.autoblog.com/2013/10/26/honda-autonomous-valet-parking-system-video/ accessed on 31st July 2019.

[9] http://www.bosch-mobility-solutions.com/en/highlights/connected-mobility/connected-and-automated-parking/ accessed on 31st July 2019.

in various media in France[10].

In 2018, Mercedes-Benz in cooperation with Bosch realised AVP in the parking garage of the Mercedes-Benz Museum in Stuttgart, Germany[11,12]. The parking garage is equipped with camera sensors to find empty parking spots and to route the automated and connected vehicle from the drop-off area to the empty parking spot. A smartphone application is used to send the vehicle from the drop-off area to the empty parking spot.

The successful cooperation between the automated vehicle and the infrastructure in Autonomous Valet Parking was demonstrated by DLR at the main station parking in Braunschweig in 2013. In this scenario, the vehicle was connected to camera sensors of the AIM test site to detect free parking spots[13]. TNO has executed several projects in the field of autonomous driving, such as an Autonomous Valet Parking proof-of-concept focussing on path tracking control. Other research projects combine AVP functions with E-mobility solutions, like the European V-Charge project[14]. In the project AUTOPILOT, AVP is used to facilitate automated driving functions by IoT. IoT applications like route optimisation based on a Park Management System (PMS) can improve safety and efficiency compared to the traditional AVP approach described above. With IoT the vehicle can be sent to a specific parking lot from any location. An end user doesn’t even have to be close to the vehicle to drop-off or pick-up the car, which allows the end user to utilize his/her time more efficient. Furthermore, the end user doesn’t enter the parking area any more leading to the situation that no human beings can be harmed by parking cars. Finally, due to the IoT technology using drones as IoT devices it is possible to set up a temporary parking area, for example for huge events like festivals. In this scenario, empty parking spots can be identified with the help of drones as IoT objects to park vehicles efficiently using the existing space. After the event the parking area is easily dismantled, and the drone is boxed and that’s it.

2.1.2 Highway Pilot

2.1.2.1 Function Description

Highway Pilot explores the use of IoT in the context of Road Hazards. The term “Road Hazard” often refers to a wide range of events and situations:

- emergency braking vehicles / slow vehicles;
- stationary vehicles (breakdowns or accidents);
- fast approaching emergency vehicles;
- traffic jams and queues;

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[10] https://youtu.be/RnsqH1DYirQ, accessed on August 20th, 2019.

[11] https://www.bosch.com/stories/automated-valet-parking/ accessed on 31st July 2019.

[12] https://www.daimler.com/innovation/case/autonomous/driverless-parking.html accessed on 31st July 2019.

[13] Löper, Christian; et.al. (2013): Automated Valet Parking as Part of an Integrated Travel

Assistance. In: IEEE (Hg.): Proceedings of the IEEE ITSC 2013. IEEE Intelligent

Transportation System Conference. The Hague, The Netherlands. IEEE, S. 2341–2348.

[14] http://www.v-charge.eu/ accessed on 31st July 2019.

- road works / route modifications;
- nearby presence of bicycles or pedestrians;
- fallen objects (from vehicles, from trees);
- road defects (potholes, bumps, gravel);
- weather related road changes (puddles, ice);
- etc.

Anticipation of the above (by way of some warning alerts for instance) is useful on all types of road environments, and even more so in a highway context where vehicles move at high-speed resulting in reduced reaction time.

Furthermore, anticipation benefits all modes of driving:

- In Manual Driving mode, thanks to experience, drivers learn to handle sudden hazardous situations. However, a sudden action from a driver (ex: trajectory change or quick deceleration to avoid a road hazard) may impact the surrounding traffic. As for driving with Assisted Driving functions (SAE levels 1 and 2), studies warn about decreased situation awareness due to driver's mind-wandering or engaging in non-driving tasks, as a result of increased driving automation [15, 16, 17]. The consequence again may be late reaction.
- In Automated Driving mode (SAE levels 3 to 5), driver and passengers entirely depend on the vehicle's own capabilities. However, current vehicle sensors usually don't proactively look out for road defects (ex: ESP is a reactive system), and maps usually don't detail road defects either.

Hence the four functions that the project aims to support are:

- Detection - providing new sensors or new ways for existing sensors to perceive road surface details. Among the new ways, one can refer to the radio communication means such as cellular smartphones and vehicular-dedicated Wi-Fi (802.11p), to extend the perception.
- Learning from experience - building an a priori knowledge of the road, similar to an enriched map or to habit.
- Preventive warning - allowing non-experienced users to benefit from learnt experience
- Preventive manoeuvring - giving vehicles instructions on how to deal with the hazards (with simple steering and speed adjustments).

2.1.2.2 State of the Art

There are several systems that deliver Road Hazard Warning (RHW) in one way or another. The most common are mapping services whose warning information is:

- Delivered visually or textually
- Reported by experts (as road authorities), users (as in Waze) and statistics/analytics (as in

[15] Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence, J. C.F.de Winter (2014) (paper)

[16] Autopilot, Mind Wandering, and the Out of the Loop Performance Problem, J. Gouraud (2017) (paper)

[17] Cooperative Adaptive Cruise Control: Human Factors Analysis, U.S. Department of Transportation (2013) (report)

Google Maps)

- Already available commercially

Another one is the iRap classification that assesses the quality of road sections and assigns a ranking. This ranking may be used by map providers to reflect hazardous areas on maps and by end users to exert extra care when needed.

More interestingly, RHW has been extensively studied in C-ITS (Cooperative Intelligent Transport Systems) public projects like compass4D [18] and NordicWay[19]. In these projects, RHW is:

- Delivered as a visual indicator (see Figure 5) onto a specific On-board Unit (OBU) or a smartphone.
- Reported by the transport system, by notification from road users or by a cloud layer validating data from vehicle and/or roadside sensors.
- Made of a static message if the hazard is static, made of a variable message (see Figure 6), if the hazard is dynamic.

Figure 5: Static visual warning studied in project compass4D.

[18] http://www.compass4d.eu/ accessed on 31st July 2019.

[19] http://vejdirektoratet.dk/EN/roadsector/Nordicway/Pages/default.aspx accessed on 31st July 2019.

Figure 6: A variable warning as the vehicle approaches the event location.

In addition to these research projects, since the beginning of the AUTOPILOT project, several car manufacturers have taken steps to address RHW, leveraging on the new connectivity capability of cars:

- Volvo cars communicate to other cars when the "Warning" signal is turned on or when road is slippery[20].
- Mitsubishi localizes hazards on a lane and shares the information to other vehicles approaching the same area[21].
- General Motors relies on "vehicle-to-vehicle" technology to alert vehicles on potential upcoming hazards, like slippery roads or disabled vehicles[22].
- Several automobiles on the market, e.g. Renault Clio V, provide 'Emergency Braking' features as part of series models.

Our objective within AUTOPILOT has been a step further by:

- Making use of more diverse connected objects for better detection of road anomalies.
- Allowing for a better confirmation of minor hazards with cloud learning.
- Simplifying the integration of the many stakeholders (cloud services, map providers, traffic control centres, etc.) in a complete service.
- Advancing RHW beyond mere warning and into actual preventive driving control.

2.1.3 Platooning

2.1.3.1 Function Description

Platooning is about automatically following another vehicle at a relatively close distance. It is related to Cooperative Adaptive Cruise Control (CACC) where automobiles follow each other at Constant Time Gap or Constant Distance Gap[23]. In certain definitions[24], a distinction is made where platooning is more related to larger vehicles with the objective to reduce air drag to obtain substantial fuel savings. However, in this document we use the terms interchangeably. A platoon is also called a 'convoy'.

Driving in a platoon requires vehicles to use inter-vehicle communications to anticipate manoeuvres of other vehicles in the platoon. Several aims and motivations for vehicular platooning exist, such as improvement of traffic throughput and homogeneity, enhancement of traffic safety due to small speed variations and relative low impact velocities in collisions, and reduction of fuel consumption and emissions due to lowering the air drag. These objectives can to a certain extent already be

[20] https://wpde.com/news/auto-matters/volvo-cars-can-alert-each-other-to-road-hazards accessed on 31st July 2019.

[21] https://www.globenewswire.com/news-release/2019/05/15/1825130/0/en/Mitsubishi-Electric-and-HERE-develop-road-hazard-alert-system-to-improve-driver-safety.html accessed on 31st July 2019.

[22] https://www.theverge.com/2017/3/9/14869110/cadillac-cts-sedan-v2v-communication-dsrc-gm accessed on 31st July 2019.

[23] ETSI TR 103 298 V0.0.4 (2019-01)

[24] https://tools.ietf.org/html/draft-petrescu-its-cacc-sdo-05 accessed on 20th August 2019.

achieved by non-automated driving systems (i.e. human driver monitors the environment and may execute e.g. the steering task), although a higher level of automation is considered to contribute in a positive way. Automated driving (system performs all aspects of the dynamic driving task) can offer additional benefits in terms of comfort (relieving the driver from driving tasks) and efficiency (no driver required in vehicles).

The aim of AUTOPILOT is to demonstrate vehicular platoons (convoys) consisting of a *lead* vehicle and one or more highly automated or driverless *follow*er vehicles. The follower vehicles have automated steering and distance, i.e. lateral and longitudinal control with respect to the vehicle in front. The control is supported by advanced V2V communication, where applications exchange data and utilize the data to execute their control loops. The awareness and control of the participating vehicles and of the platoon as a whole is extended through Internet of Things based services. Apart from driving in a platoon, forming of the platoon is also part of AUTOPILOT targets. A higher-level application exchanging data through the Internet is used by the humans/drivers to form a platoon. Once a platoon is formed, the planning state is maintained by local control data exchanges, or by CACC features.

Specifically, several variants of platooning are deployed and evaluated in AUTOPILOT, see also the pilot site descriptions in Chapter 3:

- An urban variant to enable car rebalancing of a group of driverless vehicles (up to 4), involving one driver, driving the lead vehicle. The maximum speed considered is 30 km/h. The scenario implemented in Versailles starts from a car sharing site's parking lot where the driverless vehicles join the leading vehicle to form a platoon. The platoon then moves to another location, where driverless vehicles use automated parking to park at the designated parking spots.
- A highway variant at Brainport, where one or more highly automated vehicle(s) follow a leading vehicle on the highway. The scenario implemented starts with a candidate vehicle using platooning service to find a match with an approaching vehicle willing to lead the platoon. Both vehicles are given route planning and speed advice to bring them at an expected rendezvous point close to the highway between the city of Helmond and the city of Eindhoven. After the platoon is formed, the trailing vehicles drive automatically along the highway following the leader. The platoon is made aware of lane specific conditions like maximum speed and slow traffic ahead and its cruise speed is adjusted automatically by a cloud-based service that has the knowledge about static and dynamic lane conditions.

2.1.3.2 State of the Art

Platooning was demonstrated on a public road for the first time by the National Automated Highway Systems Consortium (NAHSC) in August 1997[25], with eight fully automated cars traveling together with small inter-vehicle spacing as a platoon (see Figure 7). The demonstration was held in San Diego using a 7.6-mile segment of Interstate-15 HOV (carpool) lanes. This section of the two-lane highway was equipped with magnets installed in the middle of both lanes. The magnets served as reference markers used by the automated steering control system to keep each car centred in its lane. Next to the sensors for localizing the vehicle using these magnets, the cars were equipped with on-board sensors that provided information about their on-road behaviour (acceleration/yaw & pitch rate sensors) and the relative speed and distance between the vehicle and the vehicle in front (radar). An inter-vehicle communication system formed a local area network to exchange information with

[25] Rajamani, Vehicle Dynamics and Control, 2012

other vehicles in the platoon. A communication protocol was established to allow cooperative manoeuvres such as lane changing, joining a platoon and sudden braking. Although the project met its goals, there was no direct practical path to widespread deployment. The main reasons were that at that time vehicles could not be automated easily and that a dedicated road infrastructure with magnets was required. Nevertheless, the project inspired many new research initiatives.

Figure 7: Cars of the NAHSC demonstration[25].

Since then various other demonstrations have been performed, such as in the Dutch Connect & Drive project, where Cooperative Adaptive Cruise Control (CACC) was adapted on a platoon of seven Toyota Prius vehicles in 2009-2010 (see Figure 8). The vehicles are equipped with a CACC function that uses a radar provided ex-factory. No additional sensors were installed on the vehicle apart from using the first generation of ITS-G5 communication technology and message standards.

In a later development, car following steering functionality was added, which was demonstrated on a public road in 2013. As the standard vehicle configuration and sensing capabilities are intended for Adaptive Cruise Control, the integrity level of the system is not however enough to support high levels of automated driving.

Figure 8: Platooning vehicles in the Connect & Drive project (left), and hands-free driving on public road (right).

More recently, the European Truck Platooning Challenge[26] (see Figure 9) that took place in The Netherlands in 2016 demonstrated platooning concepts aimed at future (and developed for) high levels of Automated Driving. In this challenge, all European brands participated (Volvo, Scania, MAN, IVECO, Daimler and DAF) by driving platoons on public roads. The platoon function varied between the participants, but in general they offered close distance vehicle following and some manufacturers included automated steering.

Figure 9: Truck platoon in European Truck Platooning Challenge.

The technology typically used in the European Truck Platooning Challenge consists of environmental perception using radar and camera sensors, wireless communication between trucks according to state of the art V2X standards to exchange relevant data, and a video link camera to allow the driver in the rear truck to take over when required (i.e. corresponding to SAE Level 2 Automated Driving). No infrastructure sensors were used to support the platooning function, so the platoon relies fully on on-board sensing and traffic interpretation.

In 2017 the US DoT FHWA performed a partially automated 3-truck platooning demonstration on the US Interstate 66 corridor. The demonstration also features a chain of four automobiles using CACC with V2X communication technologies. In 2017, Tesla announced plans for a ‘semi-truck’, and platoons of it[27]. The UK DfT featured in June 2019 an on-road trial of a four-truck convoy[28]. Continental and Knorr-Bremse completed a truck platooning demonstrator in July 2019. The demonstration includes the use of V2V and V2X technologies[29].

The EU project ENSEMBLE[30], started in 2018, aims at implementing and demonstrating multi-brand truck platooning on European roads with the objectives to improve fuel economy, traffic safety and throughput. Platooning will be demonstrated by driving six differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders.

[26] https://www.eutruckplatooning.com/default.aspx accessed on 31st July 2019

[27] https://www.latimes.com/business/technology/la-fi-tn-tesla-stock-20171117-story.html accessed on 20th August 2019.

[28] https://www.theguardian.com/politics/2017/aug/25/semi-automated-truck-convoy-trials-get-uk-go-ahead-platooning accessed on 20th August 2019.

[29] https://www.traffictechnologytoday.com/news/connected-vehicles-infrastructure/continental-and-knorr-bremse-complete-truck-platooning-demonstrator-project.html accessed on 20th August 2019.

[30] https://platooningensemble.eu accessed on 20th August 2019.

2.1.4 Urban Driving

2.1.4.1 Function Description

Urban Driving assisted by IoT has the main objective to support CAD (Connected and Automated Driving) functions through the extension of the electronic horizon of an automated vehicle. Thus, the vehicle can process data from external sources which enrich those provided by its own sensors (camera, lidar, radar etc.). The kind of relevant information that automated vehicles may access as IoT elements concern:

- Status of traffic lights at intersections
- Information from infrastructure cameras, for instance on the presence of pedestrians, cyclists or other obstacles
- Information coming directly from connected vulnerable road users
- Information from other vehicles captured by their own sensors and shared as IoT elements.

Taking that information into account the CAD systems will adapt their behaviour according to the additional environmental information, available through their connection to an onboard IoT platform. An urban driving scenario is shown in Figure 10.

Figure 10: Urban driving scenario.

2.1.4.2 State of the Art

After achieving an acceptable performance in highways, autonomous driving systems evaluation focused on more challenging scenarios. Urban driving adds much more complexity and difficulties for the automated vehicle. Indeed, in an urban area there are much more elements to consider such as other road users with whom the road is shared (vehicles, VRUs), intersections with and without traffic lights, roundabouts, etc. Despite this increased complexity, authorities recognised the advantages that autonomous cars would bring to cities such as improving safety, reducing pollution or/and enhancing traffic flows.

Autonomous vehicles by Google have been plying the roads around San Francisco Bay for years. With its proximity to Silicon Valley, San Francisco is living up to its early adopter reputation regarding driverless cars. More recently, Google has begun testing driverless cars in Austin, Phoenix and Kirkland. Also, Pittsburgh is establishing a reputation on the vanguard of driverless car technology. It is home of Carnegie Mellon University which is a pioneer in research into self-driving cars. The university has also recently partnered with Uber to develop a driverless vehicle for its ride sharing service. Boston is also at the forefront of the new technology, announcing a year-long test of driverless cars on city streets. The tests, which are being run in partnership with the World Economic Forum (WEF), aim to advance transportation access, safety and WEF's sustainability goals.

Meanwhile in Europe, Helsinki is running the world's first autonomous bus system. And in the U.K., other cities are performing trials of self-driving vehicles. Also, recent European projects like CityMobil2[31] or AdaptIVe[32] deployed pilots in different cities to test urban automated driving systems. Recent European project L3 Pilot tests in a large-scale, among other applications, the Urban Chauffeur function.

Considering the technology, different solutions exist. In some cases, only vehicle-based sensors are used, in other cases connectivity is added. Regarding vehicle-based sensors, sensor fusion is typically applied, e.g. radar, LIDAR, camera, GPS and motion sensors such as IMU (Inertial Measurement Units) and wheel encoders are fused. Moreover, detailed maps of the environment are used.

In terms of V2X connectivity, the most advanced systems with higher level of deployment are C-ITS, although connected mobility services are being deployed and integrated in a MaaS approach. For instance, the City of Vigo is developing and implementing their smart city platform which centralises city management services including mobility.

The data integration includes:

- Management app for the city council staff
- Citizen app for mobility, other services and city facilities
- City control panel
- Open data platform for service providers.

Figure 11: Vigo City Intelligent data service platform[33].

[31] http://www.citymobil2.eu/en/ accessed on 31st July 2019.

[32] https://www.adaptive-ip.eu/ accessed on 31st July 2019.

[33] http://www.socinfo.es/contenido/seminarios/0508smartcities7/Vigo.pdf accessed on 31st July 2019.

Figure 12: Vigo City C-ITS services.

In such a framework, the city council of Vigo is integrating the traffic light management, traffic hazards warnings and priority to special vehicles shown in Figure 12, earlier tested as C-ITS services, within their smart data management platform (see Figure 11) in order to be able to provide such data in a wider IoT approach.

The car company PSA provides a deep background in development and testing of AD solutions and connected vehicle services (see Figure 13). Those capabilities are mainly focused on interurban scenarios and V2V communication.

Figure 13: PSA automated overtaking and pedestrian detection V2V.

CTAG has developed several AD functions as collision avoidance, ACC and automated lane change together with connected vehicle services offering most of day 1 C-ITS services. In addition, early versions of connected automated functions have been successfully tested in controlled environments as V2I pedestrian detection and speed adaptation through traffic light intersections were based in C-ITS as shown in Figure 14.

Figure 14: CTAG early urban autopilot and pedestrian detection based in V2I communication.

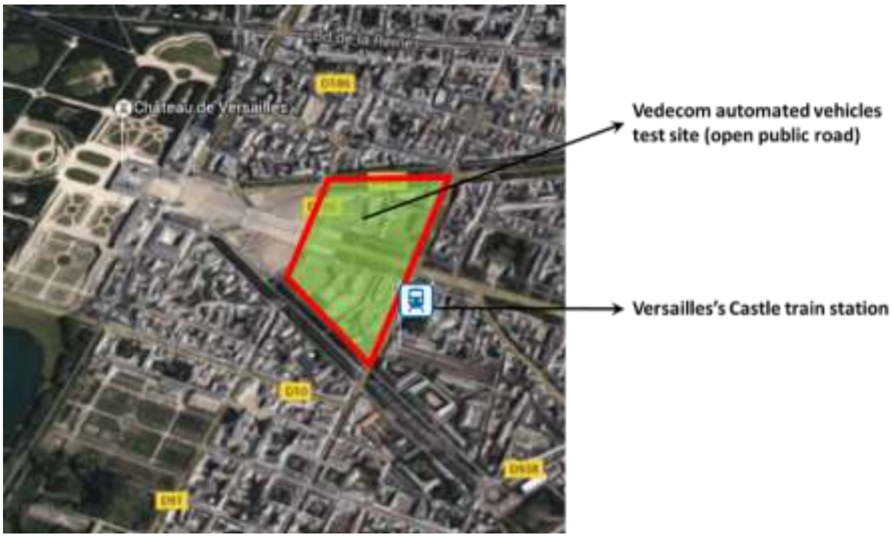


Figure 15: Versailles urban test bed of automated and connected vehicles.

The city of Versailles has also developed an urban test bed for automated vehicles as shown in Figure 15. Through its collaboration with VEDECOM, the city has already equipped 5 traffic lights on crossroads with C-ITS communication systems (ETSI G5) in the heart of the city at the feet of the famous Versailles Castle. This test bed is an area of 2 km perimeter in real urban traffic conditions.

Since November 2015, VEDECOM uses this test bed to test its autonomous vehicles (SAE L4) in real traffic conditions, see Figure 16. The tests performed are necessary to challenge newly developed or adapted algorithms in a real-life environment. Since the ITS World Congress of Bordeaux (October 2015), VEDECOM has achieved more than 2000 km of autonomous driving, on public roads in urban and sub-urban environments (Bordeaux, Versailles, Amsterdam, Paris and Strasbourg).

Figure 16: VEDECOM's AD prototypes in an urban environment.

2.2 Services for AD vehicles

2.2.1 Real-Time Ride sharing

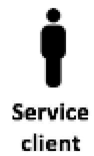
2.2.1.1 Function Description

A ride sharing service is intended as a tool to enable different customers to make use of a fleet of cars (either self-driving or not) shared amongst them. Ride sharing can be intended as a service in which multiple customers with different origins and destinations share a part of the ride in a common car (either manually or self-driven). Ride sharing services can also be considered as services that allow customers to specify pick-up and drop-off time-windows to increase flexibility and planning. Ride-sharing is also a means for semi-professional drivers to access new markets of very localized transport needs during unplanned traffic events for individuals or small groups, for brief periods of time, thus relieving a potentially overloaded or an absent traditional taxi or public transport service.

In AUTOPILOT, we think of ride sharing as a service that can offer all the above features, allowing customers to specify their origins and destinations, time windows, and preferences, such as whether they want to share the ride with other people. The service takes as input customers' requests, and based on those, outputs ride sharing schedules (plans) including pick-up and drop-off locations and times for each passenger, itineraries, etc. Unlike similar existing solutions, AUTOPILOT's ride sharing focuses on building an IoT-enabled service to showcase the potential of integrating into the growing IoT eco-system. Optimal vehicle-costumer matches are calculated using information ingested from these IoT-services, such as traffic. Moreover, cars will be able to share information relevant to each other's journeys. They will benefit from the openness of the IoT platform to receive relevant information from any device that is available in the network (traffic lights, drones, other car sensors, etc.) without the need for cars to know what each device is and/or how it operates. This opens the possibility of orchestrating other services from ride sharing. For instance, if two or more vehicles' routes, as planned by a ride sharing service, overlap in time and space, opportunities for vehicle platooning can be identified. Another example is the use of Automatic Valet Parking for the first customer that goes into the car as a driver. These two example capabilities were demonstrated during the 2019 ITS Europe Congress in Eindhoven[34].

2.2.1.1.1 Functionality overview

Customers will request pick-up and delivery at specified locations for specified time-windows



The service will need to know:

Basics

- Location
- Origin/destination/time
- Ride alone or share-a-ride
- Passenger or driver

Optional

- Time-windows specifications
- Vehicle features selection/capacity (luggage)
- Accessibility

2.2.1.2 State of the Art

2.2.1.2.1 Introduction and available ride sharing services

Ride sharing, in some instances also referred to as carpooling, started most likely in North America during WWII, when the US government required ride sharing arrangements where no other

[34] https://autopilot-project.eu/autopilot-library/videos/ (https://youtu.be/Vo6WZeMQtMI) accessed on 31st July 2019.

alternative transportation means were available[35]. In an even earlier deployment, the Taxis de la Marne were used by the French government to help transport troops to the front, during World War I. Nowadays, enabled with the current social technology and smartphones, it has become a wide and diverse application, where a plethora of services are available.

Companies such as Blablacar, Carma, Carticipate, Uber, Lyft or Liftshare offer ride sharing services where customers can specify origin, destination, and pick-up time on a computer or mobile application and the engine finds suitable rides for them. In fact, there are more than 600 services of this type in North America alone[26].

Several European countries and cities offer cars that can be picked up and dropped off at specified locations, as an ad-hoc car rental service. Green-wheels in the Netherlands (see Figure 17), Autolib' in France (service ended on 31/07/2018), and GoCar in Ireland are a few examples. In this document, we will refer to this type of service as car sharing, in contrast to ride sharing. Nonetheless, these terms are sometimes used interchangeably and both services are compatible, i.e. vehicles rented through car sharing could be used for ride sharing as well.

A growing number of large-scale enterprises and universities have also their own car/ride sharing services to minimise commuting times and reduce traffic. Zimride is one such service which is used by UCLA amongst others. In Europe, Politecnico di Milano and Università Statale, both in Milan, had their ride sharing service called PoliUniPool[36].

Figure 17: A car sharing service available currently in the Netherlands.

Ride sharing and car sharing services are part of the growing mobility-on-demand effort to re-think the transportation infrastructure of large urban areas. It is well-known that most urban vehicles are underutilized. A typical car would be confined to 20-30 km/h speeds and be parked 90% of the time. Several examples of how self-driving cars and car-on-demand systems could improve the utilization of the available resources by sharing vehicles amongst multiple riders have been investigated. In Agatz et al.[37], the authors focus on the Atlanta region area, while in Zhang et al.[38], examples from

[35] N. D. Chan and S. A. Shaheen, "Ridesharing in North America: Past, Present, and Future," Transport Reviews, vol. 32, no. 1, pp. 93 – 112, 2012.

[36] M. Bruglieri, D. Ciccarelli, A. Colorni, and A. Lu`e, "PoliUniPool: a carpooling system for universities," Procedia Social and Behavioral Sciences, vol. 20, pp. 558 – 567, 2011.

[37] N. Agatz, A. L. Erera, M. W. P. Savelsbergh, and X. Wang, "Dynamic Ride-Sharing: a Simulation Study in Metro Atlanta," Procedia Social and Behavioral Sciences, vol. 17, pp. 532 – 550, 2011.

Singapore and New York City are described. In the case of Singapore, preliminary results suggest that a mobility-on-demand service would meet the personal mobility needs of the entire population with a number of vehicles that is less than 40% of the current amount.

The country of Singapore is particularly interesting, since a few activities and incentives are put in place to favour the widespread adoption of IoT technologies, e.g. software and algorithms for self-driving cars (see nuTonomy).

Finally, an example of a European pilot is Mobinet[39], a ride sharing service to help elderly people with a mini-bus on-demand service in London (an older example of a similar service was tested in Berlin[40]).

Despite the widespread use of ride sharing services, some key issues remain to be addressed. Firstly, the service is often thought of as a "stand-alone" service, which is affected by the environment, e.g. traffic, but it is not pro-active about it. Secondly, cars are thought of as passive workers that pick up and drop off customers and are not part of the decision-making process.

In Figure 18 we report a sketch of the evolution of ride sharing services from early ad-hoc ride sharing solutions towards an IoT-enabled service.

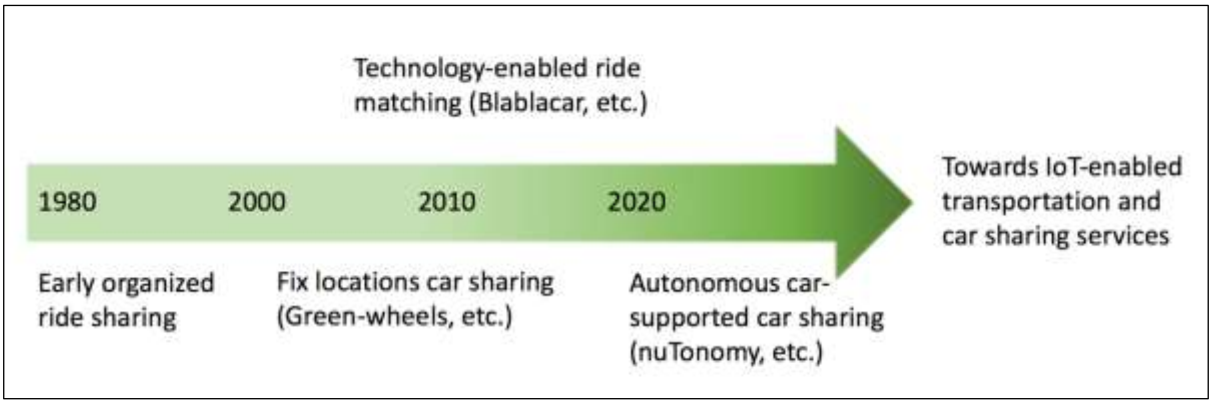


Figure 18: Evolution of ride sharing/car sharing services.

2.2.1.2.2 Algorithmic state of the art

From a purely algorithmic standpoint, ride sharing services can be formulated as dynamic, possibly large-scale, optimization problems. The underlying prototype problems are the vehicle routing problem with time windows (VRPTW) and the generalized assignment problem. Both are quite complex optimization problems the exact solutions of which are limited to small instances of the problems (around 100 customers). Heuristic solutions allow for reaching 1000-10000 customers with a carefully planned geographical decomposition of origin-destination pairs. Many surveys and

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[38] R. Zhang, K. Spieser, E. Frazzoli, and M. Pavone, "Models, algorithms, and evaluation for autonomous mobility-on-demand systems," in Proceedings of the American Control Conference, (Chicago, IL, US), July 2015.

[39] S. Capato et al., "Mobinet – Internet of Mobility," tech. rep., Deliverable 7.15, 2016.

[40] R. Borndoerfer, M. Groetschel, F. Klostermeier, and C. Kuettner, "Telebus Berlin: Vehicle Scheduling in a Dial-a-Ride System," Wilson N.H.M (eds) Computer-Aided Transit Scheduling. Lecture Notes in Economics and Mathematical Systems, vol. 471, 1999.

algorithms can be found in the literature[41,42, 43].

To scale up the possibilities of the service to handle more customers in real-time Agatz et al.[44], employ a heuristic based on the easier-to-solve assignment problem. It is interesting to note that this methodology could be enhanced by IoT-enabled cars, which would participate in solving the assignment problem by providing the costs they would incur in picking up a given customer.

2.2.2 Driverless car rebalancing

2.2.2.1 Function Description

In the concept of ride sharing / car sharing, typically these vehicles can be taken and dropped off at certain pre-defined locations. These locations (typically called *hubs*) are spread through a city and are chosen to maximise the distribution of available vehicles for people to use. Whenever a customer reserves a vehicle, the location is sent to him/her and he/she can walk to this location, whenever the vehicle is available.

However, such hubs are of course static, and the population close to hubs can at times be under (or over)-populated with ride sharing vehicles. That means that a customer might have to walk past a few empty hubs first, in order to find an available vehicle, with the implication of increased travel time and decreased customer satisfaction.

In the concept of having L4 autonomous vehicles, a rebalancing service can be used which enables that the distribution of ride sharing vehicles is optimized, based on the demand (both immediate as well as future reservations), and thereby makes sure that vehicles drive automated to these locations. In that way, these L4 autonomous vehicles can be brought to the closed hub for a customer, decreasing travel time and increasing customer satisfaction.

2.2.2.2 State of the Art

Current ride sharing services already use smartphone applications[45] that enable the customer to reserve and locate the ride sharing vehicle on the pre-defined hubs. However, at certain times it can happen that there is no vehicle available at the nearest hub, since previous customers left them at another hub already. Currently, rebalancing is done by manual labour, where ride sharing companies such as GreenWheels or Amber, have employees who drive these ride sharing vehicles to the hubs based on the following criteria:

- Available spots at a hub (typically done every evening)

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[41] G. Berbeglia, J.-F. Cordeau, and G. Laporte, “Dynamic pickup and delivery problems,” European Journal of Operational Research, vol. 202, pp. 8 – 15, 2010.

[42] Federal Highway Administration, “Real-time ridesharing,” Tech. Rep. FHWA-HRT-15-069, U.S. Department of Transportation, August 2015.

[43] U. Ritzinger, J. Puchinger, and R. F. Hartl, “A survey on dynamic and stochastic vehicle routing problems,” International Journal of Production Research, vol. 54, no. 1, pp. 1 – 19, 2016.

[44] N. Agatz, A. Erera, M. Savelsbergh, and X. Wang, “Optimization for dynamic ride-sharing: A review,” European Journal of Operational Research, vol. 223, pp. 295 – 303, 2012.

[45] https://www.youtube.com/watch?v=C2VekZJSb_I accessed on 31st July 2019.

- On demand: whenever a vehicle is requested, and the customer does not find an available vehicle at a nearby hub, the service makes sure that a vehicle is brought to the customer within a predefined time frame.

2.2.3 Car sharing and City chauffeur services for tourists

The car sharing service offers cars that can be picked up and dropped off at specified locations whereas the city chauffeur service for tourists provides an application showing tourists an itinerary in the town along the cultural points of interest (PoI). Approaching a point of interest, the application delivers an audio message explaining its location and brief history. The car sharing and city chauffeur services thus enable tourists to better see the potential of a town, and particularly to give more visibility to lesser known points of interest.

These services have been developed bearing in mind the touristic characteristic of the City of Versailles. Most of the tourists come for half a day or one day to visit the Castle and do not have the opportunity to discover the cultural heritage of Versailles, which offers a range of interesting monuments and places to visit. The estate of the Castle of Versailles extends up to 800 hectares offering different points of interest to visit apart from the Castle like the little Trianon, the great Trianon, the gardens, the fountains, the Orangery, the domain of Marie-Antoinette. Versailles also offers a variety of shops and restaurants that are ignored by tourists.

Options such as rowing boats, bikes and Segway hire, and a mini train already exist within the gardens for tourists. The car sharing and city chauffeur services enable tourists to cover wider areas and can be a nice addition to the existing options providing added values to tourists. These services can hence contribute to a better knowledge of Versailles and to the local economy.

Car sharing stations are located close to the main train station of Versailles Château - Rive Gauche and at the gate of the garden of the Castle of Versailles called Grille du Dragon in boulevard de la Reine, to be visible and used by tourists.

2.2.3.1 Function Description

The mixed concept of both car sharing and city chauffeur services for tourists intends to provide a unique experience. Through specific HMI, the tourists may access booking functionalities on their own mobile phones after downloading the application. Once he/she enters a fleet’s vehicle, the embedded HMI dedicated to the Versailles city tour guidance delivers touristic information when the tourist approaches a point of interest in his/her trip. Following user’s choices, the application provides information about the point of interests on route.

In this context the IoT eco-system will provide data enabling advanced AUTOPILOT services, such as the booking service, the vehicle restitution at the end of the trip and the touristic information given about point of interests.

2.2.3.2 State of the Art

Car sharing merged with the city chauffeur service and autonomous driving experience intends to offer a new service. There is a real interest from industry to cover the tourism market, where automotive and infotainment innovations can bring a new solution.

Companies like Easymile and Navya are offering public shuttle services on a pre-defined path thanks to autonomous vehicles. These 12-person capacity shuttles are running autonomous driving experimentation across the world and offer tourists a way to reach a specific destination, such as a PoI.

Turo is one of the companies providing a car sharing web platform allowing people to rent a car at a specific time and place. This worldwide service which creates a link between cars and drivers is accessible to anyone.

In France, Autolib is providing an electric vehicle car sharing service. This station-based fleet is available on demand and offers tourists a personal car solution.

As explained in Section 2.2.3 the car sharing and city chauffeur services of AUTOPILOT enable tourists to easily cover wider areas and contribute to a better touristic experience and also help to boost the local economy. They enable tourism-oriented infotainment which is an added value to the market.

2.3 Applications for AD

In order to realize Autonomous Driving, the support of tools from various domains in the automobile world, but not necessarily originally developed for AD functions, is needed. They provide paramount help for AD. For instance, the driving route optimization applications typically executed in the Cloud for traffic planning and surveillance can be applied to guarantee an improved path for AD vehicles. 6th sense driving and dynamic eHorizon applications help to extend sensor range of AD vehicles. The self-driving relieves humans from the driving effort and its responsibilities and requires new legislation characteristics. These can take advantage of the openings offered by a new application called Digital Driver's License, even though it has been developed for other needs than AD.

Note: The term 'Application' has multiple meanings; it can signify how other domains are applied to AD, how AD is applied to other domains, and it can signify also the software that is run in a smartphone, Cloud, or present in a Store.

2.3.1 Automated driving route optimisation

2.3.1.1 Function Description

Route optimisation has been developed as an integral part of the ride sharing service discussed in the previous section. The goal of this service is to optimise vehicle routing taking into account IoT data related to traffic information, such as average lane speed, or events, such as road closures.

Route optimisation plans routes according to ride sharing customer requests for pickup and drop-off locations. Moreover, the problems of vehicle routing and customer-vehicle assignment are tightly coupled, as the latter strongly depend on the former. Specifically, when a customer requests a ride between two locations, routes for several vehicles are calculated before pairing vehicle and customer in a predefined optimal way, e.g. minimizing the time to serve all customers. More details on this problem and the proposed solution, as well as a thorough state-of-the-art can be found in a related publication[46].

This functionality has been implemented as an extension of the Open Source Routing Machine (OSRM)[47], connected to the AUTOPILOT IoT infrastructure. This approach can be used by human driven vehicles as well as by automated vehicles.

[46] A. Simonetto, J. Monteil, and C. Gambella, "Real-time city-scale ridesharing via linear assignment problems" Transportation Research Part C: Emerging Technologies, vol. 101, pp. 208-232, 2019.

[47] http://project-osrm.org/ accessed on 31st July 2019.

2.3.1.2 State of the Art

Regarding the optimization algorithm, this application is required to solve a problem known as a single-vehicle Dial-a-Ride-Problem (DARP)[48]. This has been done in the context of the ride sharing service, thus, the previously discussed state of the art in ride sharing and ride sharing algorithms is also relevant here.

2.3.2 6th Sense Driving

2.3.2.1 Function Description

6th Sense is the a priori experience and anticipation capabilities a vehicle may have. 6th Sense Driving originally refers to the provision of road risk metrics to assess the drivability of roads. These risk metrics are computed with vehicle on-board sensors.

In the context of the AUTOPILOT project, 6th Sense Driving goes a step further, leveraging vehicle on-board sensors, other device sensors and IoT, in order to provide the actual nature and location of road hazards (not just metrics) as well as recommended driving strategies that drivers and autonomous vehicles can follow.

By doing so, 6th Sense Driving for AUTOPILOT allows drivers and autonomous vehicles to anticipate better as the information augments or complements:

- the capabilities of their respective sensors, which are in the order of a few hundred meters in good conditions, and not necessarily focused on road surface details
- their a priori knowledge of the road (e.g. from map, from habit, from risk index)
- their experience of these conditions (e.g. of traffic, of weather)

Overall, 6th Sense Driving for AUTOPILOT can be considered as an attempt to recreate and offer everyone the driving skills of a person very familiar with a specific road, who can arguably deliver the safest and most comfortable ride.

2.3.2.2 State of the Art

As presented in Section 2.1.2.2, and as seen in some commercial services (e.g. Waze), the idea of collaborative enrichment of maps, and warning users of road users is not exactly new.

State-of-the-art solutions do not propose a complete automation of the process and the capability to learn about the lesser noticeable road surface hazards. With 6th Sense Driving, the diversity of sensors on mixed IoT devices makes it possible to detect anomalies that, if reported many times over, turn into certain road hazards. The more a road is driven through, the more precise and complete the information gets.

More importantly, state-of-the-art solutions end with a user warning or alert, whereas 6th Sense Driving aims at delivering driving recommendations on approaching the road hazard. This last part is initiated by a traffic management person, who has sole authority and knowledge of the road, and hence ability to propose instructions to drivers and autonomous vehicles.

[48] J.-F. Cordeau, and G. Laporte, G. “The Dial-a-Ride Problem (DARP): Variants, modeling issues and algorithms” 4OR – Quarterly Journal of the Belgian, French and Italian Operations Research Societies 1, 89 – 101, 2003.

These recommendations are interpreted by autonomous vehicles as such (can be ignored if deemed unsafe or contrary to the vehicle rules), which is another differentiation from state-of-the-art teleoperation solutions. A future development would be to observe and learn from the driving pattern of vehicles in order to automate the creation of these recommendations.

2.3.3 Dynamic eHorizon

2.3.3.1 Function Description

The aim of Dynamic eHorizon is to provide AD systems with map content that is frequently automatically updated to reflect changes and events that occur on the road over time. Using this content, the AD systems would be able to have a fresh electronic horizon that they can rely on when taking driving decisions.

Dynamic eHorizon can address updates as well as static and dynamic changes:

- Static changes relate to permanent events the effects of which are persistent and do not often change over time (e.g. a fixed traffic sign; a new permanent road section).
- Dynamic changes relate to ephemeral events with limited and pre-defined lifetime (e.g. a water puddle on the road; a roadwork section with restricted lane).

In both cases Dynamic eHorizon is designed to trigger new map update content as soon as it is notified of an event’s occurrence. In the context of AUTOPILOT – notably in the Livorno Highway Pilot Site – only dynamic updates are considered. Dynamic eHorizon is set up to receive event notification via the IoT platform (oneM2M). Two dynamic use cases are investigated:

- Water puddles on the road along with a restricted speed limit section.
- Road work section along with a restricted speed limit section.

For both use cases the map notifications are generated and forwarded to a third-party cloud (CRF cloud), which is then responsible to forward the content to AD systems into cars.

2.3.3.2 State of the Art

There are several approaches in the industry aimed at providing electronic horizon to cars in the context of autonomous driving.

The historical way is to rely on the digital map inside the car. In this case the reliability of the electronic horizon is constrained by the ability to have digital map content that quickly includes changes that occur on the road over time. In the traditional automotive world digital maps lack flexibility to consider changes on map and dynamic events, because they typically require three months or more to compile updates in order to provide a new map version.

In order to improve the updating process of electronic horizon, in addition to the embedded digital maps, sensors have been introduced on cars. Those sensors are responsible for analysing the car’s environment and feed the AD systems with additional information on what they detect in real-time. This approach may be useful in some cases, notably with short range electronic horizon in optimal weather conditions. Nevertheless, information provided by sensors is not 100% reliable. The range of sensor “visibility” is also rather limited (up to 300 meters approximately in the best case). It is thus a common approach to fuse information provided by sensors with information from other sources to create an electronic horizon that is more reliable, covering a better range of visibility (up to many kilometres).

Today's trend on improving the freshness of electronic horizon is to rely on digital maps that can be updated more frequently than the historical ones. This new generation of digital maps needs to gather information from various sources, such as weather stations, traffic control centres, RSU (Road Side Unit) and various other sources, to provide map content taking into account recent changes on road conditions. The way to gathering and compiling such information from different sources is an active field of research. For the AUTOPILOT project, the challenge is to investigate how using IoT connectivity – and notably the oneM2M IoT platform – to gather and propagate dynamic information could advance autonomous driving. In this context Dynamic eHorizon is responsible for receiving traffic information updates and processing them to generate new map content that takes in account the associated changes.

2.3.4 Digital driver license and driver license virtualization

The digital driver license application, along with its related services, is an addition to other automotive platform services to increase both security of the services and user acceptance. It provides user identity with high level of assurance that enables trust among the users (e.g. in car sharing) and also secures user authentication needed for access to web and IoT services.

2.3.4.1 Function description

Digital driver license is an example of next generation official citizen document, implemented not in a physical chip (embedded in plastic card or booklet), but through an App that stores the information in the user's smartphone instead. The motivation to introduce this concept was:

- to provide a document that can be immediately updated on the go,
- to increase usability by removing the need for the user to visit governmental offices in case of expiration or personal information change,
- to provide additional services such as notification of fines or organizational changes by the document issuer.

The digital document is used in the same cases as the electronic one: face-to-face identity verification, proof of age and online authentication. The issuer is also the one who provides all necessary services including authentication server. Even though there are usually means to limit information sharing, the government services often collect all the information and this fact may be perceived as not privacy friendly and may impact user acceptance. This is an issue that may be addressed by the document virtualization technique.

In case the user does not want to use an official document for authentication, but the service still requires high assurance identity, the user may use a new identity that is created based on his/her electronic or digital document, but contains only a limited subset of the identity information. Typical case is the proof of age: the new identity contains only information about age and a security mechanism that provides an opaque link to the original document. Even if the environment is not trusted the user never discloses more than exactly what he/she approved.

2.3.4.2 State of the art

Digital driver license and digital documents in general are a very new concept. There is an initiative ISO 18013-5 (Information technology -- Personal identification -- ISO-compliant driving licence -- Part 5: Mobile driving licence application (mDL)) that defines structures and protocols for digital document verification. Two use cases are face-to-face verification and remote web authentication, in both of which the user presents his/her document to a verifier to prove his/her identity or certain attribute.

The use cases in the specification are approached from two points of view: offline and online documents.

Offline documents are similar to electronic documents: the smartphone App contains structure similar to the ICAO passport. The document contains information organized into data groups, the data are signed by SOD structure and the document contains a dedicated key pair for active authentication. The advantage of this approach is that the document may be verified even if the user's smartphone and the verification terminals are both offline. The document is stored in the smartphone, so security of this solution fully depends on security measures implemented by the smartphone native API and the App.

Online documents are implemented by a lightweight App working as an authentication device and a server side that provides user information. The online verification use case involves an App that produces a vendor specific access token and shares it with the verifier. The verifier then contacts a specific web endpoint provided by the document issuer to resolve the opaque token into a structure with personal information. This solution is much simpler than the offline version because it removes the need to provision the document into the user's smartphone, so the development and deployment is much shorter.

2.3.4.2.1 Document virtualization and identity derivation

Identity derivation or document virtualization is a technique to transform an existing document into a new authentication token. A new credential (such as RSA key pair) is are created and cryptographically linked to the information and credentials of the original document. Advantages of this approach are that the new identity may be issued by different organizations, so it does not depend on the government; the identity may be only partial (containing only selected parts of the document) to be privacy friendly; and it may utilize innovative cryptographic schema because the new identity does not have to be widely interoperable.

The typical derivation may use asymmetric cryptography as a main credential technology and also as a link between old and new information: the key stored in the document is used to sign the new credential thus providing evidence of the user's consent.

Advanced solutions may use more advanced cryptographic concepts such as zero knowledge proof technologies. In this case the new identity may provide a cryptographic proof of user attribute (such as age or driving eligibility) without disclosing any other information (including public key). These schemes provide full anonymity while providing strong proof of the information. Typical examples of the zero knowledge technologies are U-Prove by Microsoft and IDEMIX by IBM.

The App may usually hold multiple separate identities and credentials and work as an identity wallet.

2.3.4.3 Identity derivation in Automotive use cases

Authentication with digital documents may be used for automotive use cases without any further modifications, but this would limit usage of the services to citizens having an official document and would be an obstacle for foreigners or people without driver's license. From this point of view the document virtualization seems to be a better choice.

Strong authentication provided by virtualized documents is a valuable service for the automotive use cases in general. The attribute sharing and need of trusted personal information is usually limited to a few cases that may be needed because of legal obligations or incident resolution. Typical examples of required attributes are age, citizenship or driving eligibility.

The virtualized document may be used in a basic case when the user interacts with web services such as ride sharing or automated valet parking. In this case the authentication result is used by the vendor App to access the server side. An additional opportunity is to use the App as credential wallet for local authentication use cases such as opening of car keys.

3 Specification of Pilot Sites and Use Cases

AUTOPILOT includes six pilot sites, five in Europe, namely Tampere – Finland, Versailles – France, Livorno – Italy, Brainport – Netherlands and Vigo – Spain, and one in Daejeon – South Korea.

For each pilot site, the general description of the site, the deployed use case storyboards, related services and IoT utilisation are described in the following sections.

3.1 Finland - Tampere

The AUTOPILOT pilot site in Finland is in Tampere, in the town district of Hervanta, at and near the premises of VTT as shown in Figure 19.

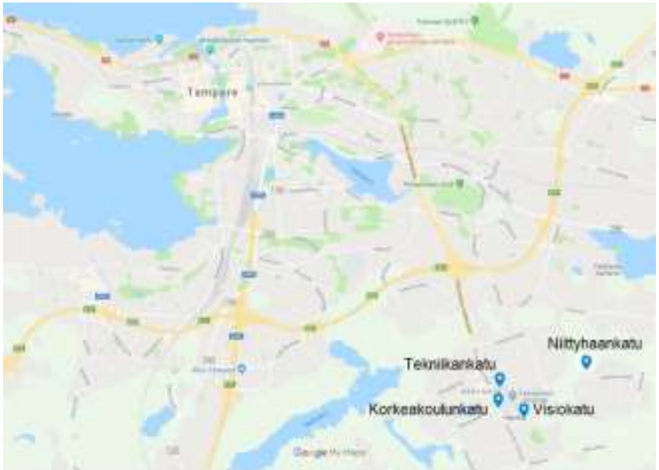


Figure 19 Location of the test site in Tampere.

The vehicles used in the AUTOPILOT pilot site are VTT research vehicles. VTT has two research vehicles, a Citroen C4 (“Marilyn 2.0”) (Figure 20, left) and a Volkswagen Touareg (Martti), which have been converted by VTT for automated driving. Both research vehicles act as an innovation environment for testing of sensors and automated driving functions. The vehicles have been designed for different environments: Marilyn for urban environments and Martti for testing in harsh environmental and industrial environments. Marilyn 2.0 was adapted to support the functions needed for the AUTOPILOT project, including the in-vehicle IoT support, reverse driving and interaction with traffic lights.

Figure 20. VTT’s research vehicle Marilyn 2.0 and the mobile road side unit MARSU

VTT also has a mobile roadside station, called MARSU (Figure 20, right) on which roadside infrastructures, such as V2X equipment and the camera, are installed. The traffic camera image is processed locally in the mobile station MARSU.

At the beginning of the AUTOPILOT project, the research vehicle had been tested for simple traffic scenarios, including following programmed tracks and V2X communications. This has been extended to cover two use cases conducted on the Tampere pilot site. The use cases considered were:

1. Urban driving focused on the intersection Hervannan Valtaväylä-Korkeakoulunkatu. The use case was also tested next to the VTT facilities in Niittyhaankatu.
2. Automated Valet Parking (AVP) implemented on the VTT facilities, in which a special area is reserved for accommodating the service. The use case was demonstrated at VTT's former facilities in Tekniikankatu and was piloted with test users in Niittyhaankatu.

3.1.1 Use Case 1: Urban Driving

3.1.1.1 Storyboard

When the vehicle approaches a signalised intersection, the vehicle receives real-time information on the status of the traffic light from the back-end system, and adapts its speed based on the available information.

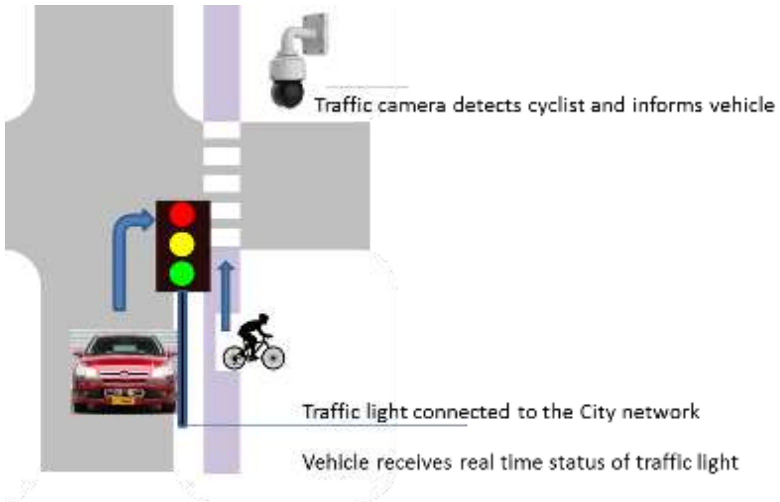


Figure 21: Urban driving scenario with intersection support in Tampere.

At intersections, there may be conflicts between road users that have green simultaneously, e.g. between cars turning right and VRUs crossing at the pedestrian crossing. A traffic camera located at the intersection detects road users which are on a potential collision course with the cars - such as a pedestrian waiting to cross - and sends this information to the IoT platform. The car receives the information and takes an appropriate action, such as giving way to the pedestrian. An illustration of the scenario is shown in Figure 21.

3.1.1.2 Description specifying AD driving mode, services and applications

To enable this use case, the vehicle exchanges information with different IoT sources, such as the traffic lights and the traffic camera. The traffic light provides information on signal phase changes while the traffic camera provides information about whether there is a VRU in a danger zone.

In the city of Tampere, information from traffic lights is available from the City of Tampere traffic network. For 80 signalised intersections (55% of all signalised intersections) real-time information is currently available, and the other intersections are planned to be integrated in the near future. The real-time information is provided by the traffic light system provider, Dynniq. In the Hervanta district, information is available for two traffic lights, including the Hervannan Valtaväylä-Korkeakoulunkatu crossing. Hervannan Valtaväylä is a suburban road with two lanes in each direction, with maximum speed limit of 50 km/h. There is a separate cycle track at the east side of the road, which is used by students and personnel working in the Hermia region.

3.1.1.3 IoT Utilisation

Automated driving support using traffic cameras

In the AUTOPILOT project the use of traffic cameras for assisting automated vehicles has been demonstrated. Traffic cameras are being installed by the City of Tampere at major intersections. The AUTOPILOT project tested the same type of camera for tracking of road users that are on conflicting routes with the automated vehicle at intersections and parking places, and that are outside the field of view of vehicle sensors. A typical example is a bicyclist driving straight on a separate lane to pass through green while a vehicle - also having green - turns right. Another example is when the automated vehicle is parking in an area where other road users can also walk freely, e.g. pedestrians walking to their own car.

Signalised intersection support

The Finnish pilot assessed how the vehicle can communicate with the traffic light control system, by using cellular communications. Traffic light controllers communicate in real-time to the traffic network of the City of Tampere. Information from the network is retrieved by the automated vehicle for adapting speed near the traffic light. This method will allow cities to deploy C-ITS at traffic lights without the need to install additional hardware.

3.1.1.4 Hypotheses on IoT impact

- A more reliable perception of traffic light status for speed adaptation and higher in-vehicle comfort
- Wider range of information of route traffic lights and potential adaptation of route speed
- Anticipation improvement with extended perception beyond own vehicle sensor range
- Safer reactions in the presence of pedestrians and hazards
- Smoother driving behaviour

3.1.1.5 Suggested Performance Indicators

- Number of hard acceleration events comparison
- Number of hard braking events comparison
- Time of detection of pedestrian by the vehicle

3.1.1.6 Sustainability of the pilot site and functionalities developed after the project

The functionalities developed for this use case will be used in future projects, e.g. in projects regarding communication for different types of crossings, where the vehicle should yield for other road users. Using camera or other sensors, the vehicle receives information whether he can proceed or has to stop prior to the crossing.

3.1.2 Use Case 2: Automated Valet Parking

3.1.2.1 Storyboard

Automated valet parking is demonstrated at VTT facilities, first in June 2018 at the former VTT premises in Tekniikankatu, and in Autumn 2018 at the new facilities in Niittyhaankatu

The automated vehicle drives the user to the drop-off point (see Figure 22). It then reserves a parking space. A traffic camera, of the same type as the camera used for intersection support, verifies the availability of the reserved parking space and detects the presence of any other road users on the potential route to the parking place. After the driver has left the vehicle, the parking manager (or alternatively the driver using a mobile application) ascertains that the vehicle is ready for parking and the vehicle drives autonomously to the reserved parking place.

If the driver wants to collect the vehicle at the pick-up point, the driver (or the parking manager) sends the request to the vehicle, which returns to the pick-up point.

A video of the public demonstration of the service in Tekniikankatu is available[49].

Figure 22: Parking lot at Niittyhaankatu where the AUTOPILOT Automated Valet parking was piloted.

3.1.2.2 Description specifying AD driving mode, services and applications

To enable this use case, the vehicle exchanges information with traffic cameras. The traffic camera provides information whether there is a VRU or object in the projected vehicle path and whether the parking places are free or occupied.

The AUTOPILOT Finnish pilot site team collaborates in Tampere with the H2020 TT (Transforming Transport) project on the use of big data in transport. TT (Transforming Transport)[50] is a H2020 project, which started in 2017. The Urban Mobility pilot in Tampere has as main objectives to improve the situational awareness in the city of Tampere by providing tools for the urban Traffic Management Centre and by providing more quality information to drivers and public transport users. A second objective is to find solutions for improving urban mobility. A solution that has been developed to mitigate the planned reduction of parking places in the city centre is a parking place reservation system for goods delivery. The parking place reservation system, which has been developed by Mattersoft is also used for the autonomous vehicle for reserving parking places.

During the development of the AVP use case, VTT also collaborated with HERE. VTT tested the UWB

[49] https://www.youtube.com/watch?v=rfu2w1KzJak&feature=youtu.be accessed on 31st July 2019.

[50] www.transformingtransport.eu accessed on 31st July 2019.

positioning method from HERE, which was demonstrated together with HERE in an underground parking (https://www.youtube.com/watch?v=SODPKgDomaQ). For the actual pilot, RTK-GPS was used which gives similar accuracy in outdoor conditions and does not depend on outdoor battery-powered beacons.

3.1.2.3 IoT Utilisation

In the AUTOPILOT project the use of traffic cameras for assisting automated vehicles has been demonstrated for both use cases. For Automated Valet Parking, the camera detects whether there are objects on the projected vehicle path and if the parking places are occupied.

3.1.2.4 Hypotheses on IoT impact

- IoT makes the AVP use case more efficient, expressed in reduced travel times for drop-off and pickup.
- IoT increases safety by allowing access to additional sensor information.

3.1.2.5 Suggested Performance Indicators

- Time to park
- Waiting time / time to return vehicle
- Latency of detection

3.1.2.6 Sustainability of the pilot site and functionalities developed after the project

The functionalities developed for this use case will be used in future projects, e.g. in projects regarding automation of industrial vehicles, especially for use cases requiring accurate positioning near loading and delivery points.

3.2 France – Versailles

In Versailles, the goal is to provide a mobility service dedicated to touristic applications. Based on a small fleet of three automated vehicles provided by VEDECOM and dedicated to a car sharing application, the French pilot site experiments a high level of connectivity (fleet management operations and POI notifications) and automated touristic tours.

Two use cases considered at Versailles are i) an urban driving with car sharing and city chauffeur services for tourists and ii) platooning for driverless car rebalancing. The former has user-centric focus whereas the latter has operator-centric focus.

3.2.1 Use Case 1: Urban driving with car sharing and city chauffeur services for tourists

3.2.1.1 Storyboard

A user can book a vehicle at one of the two AUTOPILOT car sharing stations. To do so, she/he uses the AUTOPILOT smartphone application. She/he can then drive the car to head to whichever destination inside the city or activate one of the touristic trips suggested by the navigation system. During a touristic trip the user receives audio POI notifications to discover the city of Versailles whilst manually driving the vehicle. The HMI inside the vehicle (through HMI in the vehicle) provides all the relevant information in a user-friendly way as shown in Figure 23. At some point in the trip, the automated driving mode can be switched on (in the Castle's garden, see Figure 23.). In AD mode, the system uses IoT to enhance the detection of VRUs. At the end of the AD zone, the user is asked, via the embedded HMI screen to take back the control of the vehicle. At the end of the trip the user parks the vehicle at one of the stations (end of the trip validated through the smartphone application).

Figure 23: Versailles Pilot site: HMI concepts for AD.

3.2.1.2 Description specifying AD driving mode, services and applications

Table 2: Mapping of use-case to AD modes, services, and applications listed in Chapter 2.

Automated driving modes	Services	Applications
Urban driving	Car sharing and city chauffeur services for tourists	None

The urban driving mode is split into two:

- Connected manual driving and
- Fully automated driving

Users of car sharing and city chauffeur services for tourists have the opportunity to pick up a vehicle at one of the two car-sharing stations (close to Versailles Rive Gauche train station in front of the city hall and close to one of the castle's gardens main entrances at hotel Trianon palace). With the agreement of the "Château de Versailles", a dedicated tour (in a controlled area) is implemented in the castle gardens around the Pièce d'Eau des Suisses lake. During this tour, the end users experience L4 (Level 4) automated driving as well as dedicated connected services such as city chauffeur service.

When driving in the connected manual mode, the vehicle is connected to city chauffeur services which provide Point of Interest notifications on public roads in Versailles. In general, POI notifications are a set of announcements, or informal alerts, that are generated automatically based on close range detection of an interesting touristic spot. It is considered that the vehicles can detect the spots in close range and that the announcements are issued to the users of the vehicles. The detection technologies are based on IoT devices and include:

- Automatic detection of geo-coordinates, using localisation technologies such as satellite reception, or hybrid satellite-odometry measurements. These coordinates are compared to a database of pre-recorded interesting spot coordinates and announcements are made when the distance is small enough.
- Visual pattern matching of landmark architectural traits, or of pre-installed computer-generated signs such as QR-codes, against a database of pre-recorded images.
- Echo detection of radio signal from pre-installed RFID devices on certain buildings, statues, or other infrastructure close to a point of interest.
- Rich-data beacon signals emitted by dedicated computing and communication units (RSU, Wi-Fi hotspot, Bluetooth point) situated very near the interesting spots.

Each POI detection technology has different characteristics in terms of range and precision of detection, resistance to interference, algorithm complexity, line-of-sight and data storage, and Internet access requirements.

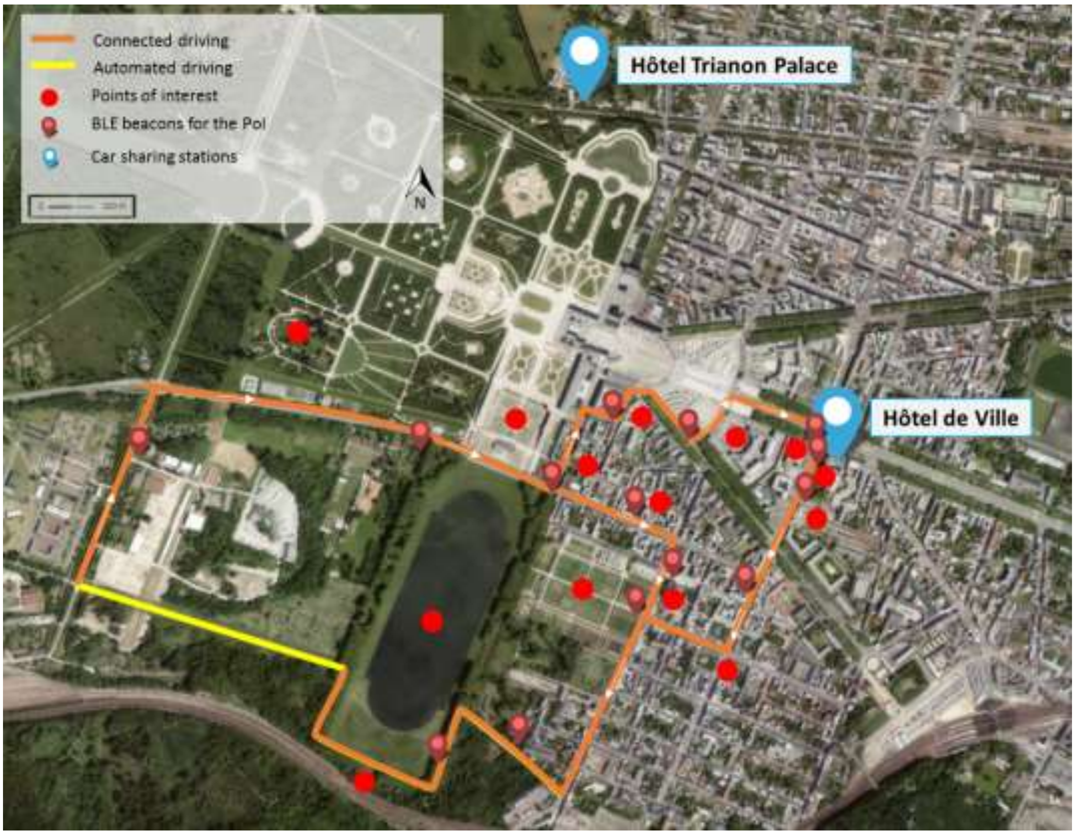


Figure 24: Versailles Pilot site overview: Urban driving

Figure 24 shows the 14 points of interest that have been selected for Versailles' urban driving use case: Hôtel de Ville, Gare Versailles Rive Gauche Château, Carré Saint Louis, Potager du Roi, Pièce d'Eau des Suisses, Statue Equestre, Grille des Matelots Les bosquets du jardin, Château/Orangerie, Salle du Jeu de Paume, Cathédrale Saint Louis, Grande bibliothèque, Cours des senteurs, Petite écurie, Office de tourisme.

These points are located on the urban driving route followed by the vehicle. Bluetooth Low Energy (BLE) beacons are used for the detection and audio broadcast. In addition to these historical places and monuments, other BLEs could have been installed near local businesses such as restaurants or shops.

In the fully automated driving mode, the vehicle is driving in the castle's gardens in an area shared with VRUs. A collaborative perception approach is used to support this driving mode. Collaborative perception considers information exchange among road participants to enhance the usual perception capabilities of standalone users (vehicles and VRUs). Particularly, the safety of VRUs can be improved by the collaborative perception since both vehicles and VRUs are collaborating (communication exchange through the oneM2M IoT platform) and informed in case of a safety-critical situation.

The goals of the collaborative perception can be listed as follows:

- Augmenting the local perception of vehicles by merging the information obtained from the communication (including IoT platform)
- Warning VRUs on a potential danger by using connected objects and dedicated services which analyse the collision risks with AD vehicles (smartphones, smart wearable devices, OBU for bicycles)

- Comfort and information services which can be provided to the pedestrians such as the advertisement of autonomous driving vehicles, tourist guidance, etc.

3.2.1.3 IoT utilisation

Pedestrians and bicycles pose important safety issues to automated vehicles on open roads. To mitigate this, the proposal is to use other connected objects (vehicles, smartphones, traffic lights, cameras, etc.) to improve VRU detection. Smart devices are carried by the vulnerable road users. Each vulnerable road user who is part of the project is considered as an IoT object due to his/her smart device or OBU on the bicycle. The pedestrians wear smart devices such as smartphone, smartwatch and smart-glasses. The bicycle is equipped with an on-board unit and a speed sensor. VRUs are capable of communicating via 3G/4G, LTE and 802.11 b/g/n networks. For pedestrians, the communication gateways are their smartphone. All wearable sensors receive/transmit data wirelessly from/to the smartphone. For bicycles, the communication gateways are the OBUs installed in the front basket of the bicycle.

A draft architecture of the collaborative perception platform is given in Figure 25. The collaborative perception platform targets the following key objectives:

- Use of a combination of wearable, on board and roadside sensors, with short range and direct Wi-Fi communication.
- Absolute position and intention detection estimated by a fusion of GPS, kinematics sensors and RSSI measurements, through an IoT cloud-based service.
- Tight collaboration with VEDECOM (vehicles) and roadside infrastructure (access to vehicles CAN-bus, infrastructure input, etc.).

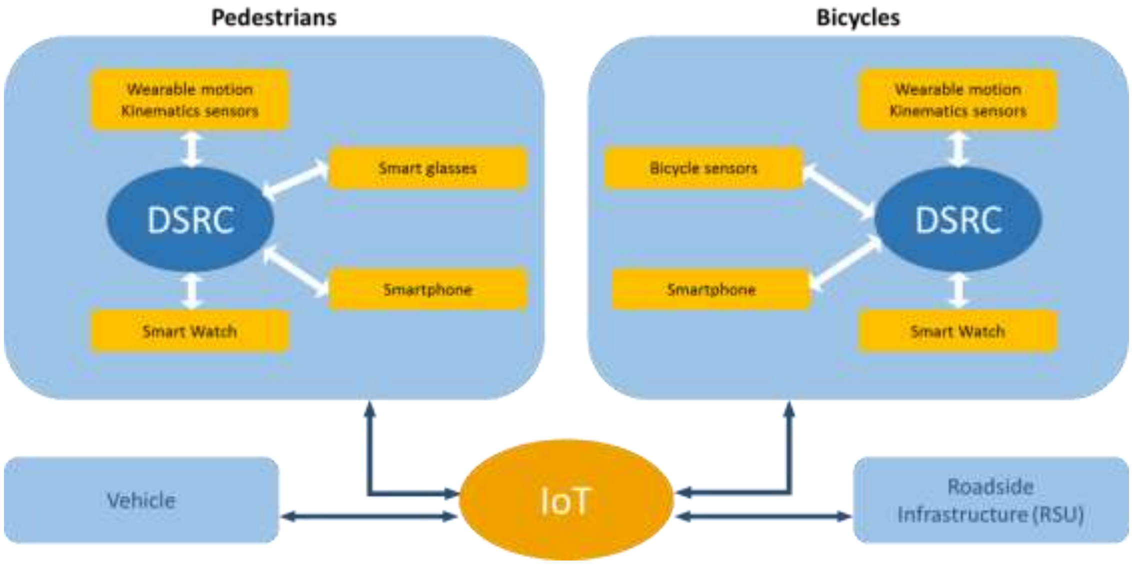


Figure 25: Draft architecture of the collaborative perception platform.

AUTOPILOT pedestrian app has been designed for Android as well as iOS versions [51,52].

[51] AUTOPILOT pedestrian app at Google Play available at https://play.google.com/store/apps/details?id=autopilot.certh.gr.pedestrian accessed on 31st July 2019.

[52] AutopilotVRU at Apple Store available at https://itunes.apple.com/us/app/autopilotvru/id1413711648 accessed on 31st July 2019.

3.2.1.4 Hypotheses on IoT impact

- IoT helps the vehicle to detect vulnerable road users.
- IoT helps the vehicle to anticipate dangerous situations.
- IoT warns VRUs of an approaching AD vehicle.

3.2.1.5 Suggested Performance Indicators

- Pedestrian presence is detected at a greater distance by IoT automated vehicle
- Reduction of speed of the AD vehicle when approaching a VRU.
- Reduction of the number of hard braking due to anticipation - thanks to IoT.

3.2.2 Use case 2: Platooning for automated fleet rebalancing

3.2.2.1 Storyboard

The idea here is to enhance fleet management through automated fleet rebalancing with the help of IoT technologies. Intelligent algorithms in the car sharing back office can optimize the number of vehicles needed in each car sharing station to deliver a high-quality service to the end user.

Data collected by the back office (mostly booking and charging status of vehicles, and historical data on usage of the service by time) are analysed by smart algorithms to provide a recommendation of the number of vehicles to rebalance and to which station.

After the back office has allocated each vehicle to a station, the vehicles can start to move: A human operator arrives to the station and sends the order to move the selected vehicles to another station. The vehicles move in AD mode and set up a convoy behind the lead vehicle driven by the operator.

3.2.2.2 Description specifying AD driving mode, services and applications

Table 3: Mapping of use-case to AD modes, services, and applications listed in Chapter 2.

Automated driving modes	Services	Applications
Platooning Automated Valet Parking	Driverless car rebalancing	None

To study the improvement of the business model of car sharing, a platooning application is introduced in the streets of Versailles to experiment automatic fleet rebalancing between the two car sharing stations. The vehicles also have an Automated Valet Parking mode that enables the operator to collect the vehicles at the starting point of platooning or send them to their designated parking spots while reaching the destination car sharing station.

An overview of the itineraries for platooning in the French pilot site is shown in Figure 26. In Versailles for the iteration that took place in July 2019, the use case implemented and tested was as follows: The first vehicle of the platoon is driven by a human operator. The maximum size of the convoy is three vehicles (one leading vehicle + two AD vehicles) and the maximum speed is set to 20 km/h. The distance between the vehicles increases with the speed of the platoon whose total length is 11m at stand-still and 21m when driving at 20km/h.

During trials, a dedicated HMI is installed in the lead vehicle to inform the driver whether it is permitted to continue the trip at a traffic light considering time to red and/or time to green keeping the platoon complete or to stop at a traffic light in order not to split the platoon. The duration of current traffic light status is displayed and the duration for the platoon to cross the intersection is calculated.

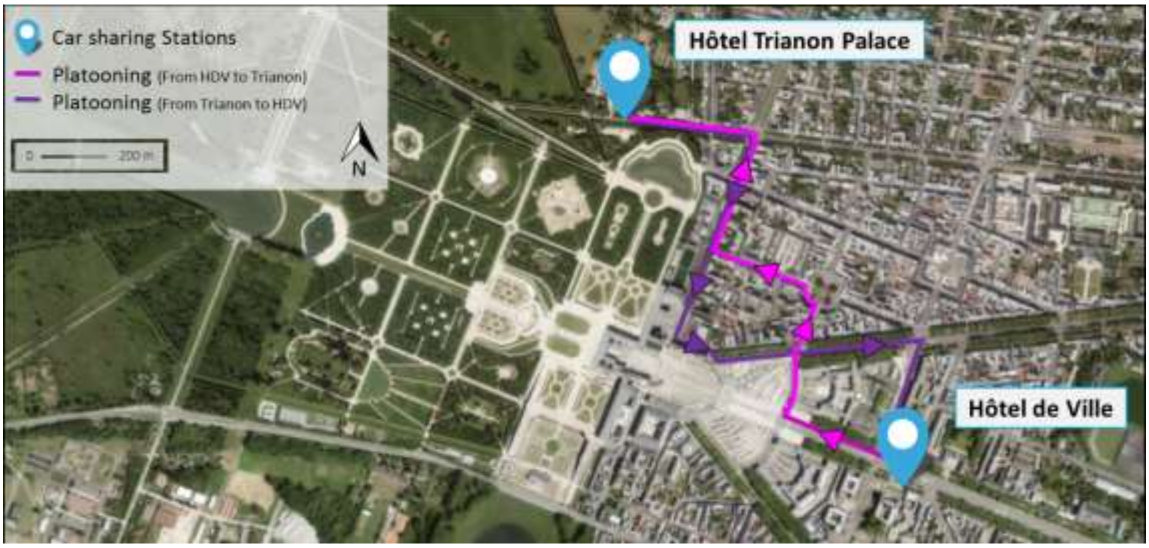


Figure 26: Versailles Pilot site overview: Platooning

When driving from one car sharing station to the other, different scenarios can be faced by the platoon, such as:

"Start up the platoon": Start moving in the platoon mode. The platoon has been formed: the vehicles are in their predefined places and the distance between them has also been defined. The local communication among the AD vehicles and the lead vehicle has been established and maintained. The trajectory to follow is clear. The platoon can start to move forward up to the speed limit of 20 km/h.

"Drive the platoon in normal platooning mode": Driving the platoon according to the speed of the lead vehicle and maintaining the designed inter-distance. The platoon has started moving: each AD vehicle estimates the distance to the vehicle ahead; no failure detected, no obstacles on the road. The lateral controller keeps the AD vehicles in the predefined trajectory. When the lead vehicle brakes at a red light, the following vehicles do so too; when receiving the information on the status of the traffic lights, the lead vehicle crosses the intersection, followed by the two other vehicles.

"Emergency stop": Stop the platoon in emergency situations. The platoon is following the lead vehicle to the destination and the traffic conditions are normal. A failure or critical situation is detected in the platoon: An emergency stop command is sent. All AD vehicles activate the emergency break and switch on the hazard lights. They stop without having a collision and change to the waiting mode.

3.2.2.3 IoT utilisation

The automated rebalancing of the fleet of vehicles is performed using platooning technology with a lead vehicle driven by a human driver. The lead vehicle receives the following information through the cloud application:

- Identification of the vehicles that form the platoon. The fleet operator uses the app to send a request in order to know which vehicles have to be moved from one station to another. The information is the result of a data analysis based on the following inputs:
    - Vehicle battery autonomy
    - Trip cycle time and history versus time/day period
    - Parking base and reload station free space
- Messages displayed on the HMI:

- Stop / start line-up of the platoon: for each vehicle to line up behind the lead vehicle; then the operator checks if all the vehicles are lined up successfully.
- A message is displayed on the HMI once a vehicle has joined or left the platoon.
- During the platooning: speed, time needed to pass a road crossing. This information is received via the "platoon component" (see TLA description below).

Traffic Light Assist (TLA) helps platoons cross traffic lights without splitting thanks to IoT technologies. By collecting data from traffic lights and vehicles, a recommendation can be provided informing the leading vehicle if it should cross or stop.

IoT data are stored in the oneM2M platform as a database. TLA is connected to it through a notification system that allows it to react at each new incoming data. TLA provides several functionalities like platoon supervision, data collection or decision generator. Relevant data like car positions or traffic light state are collected from the platform and injected into a decision generator algorithm that is then convoyed to the leading vehicle via the platform. This decision is determined according to the closest traffic light's current state, and next time change as well as the time remaining for the lead and last vehicles to reach the traffic light. The outcome is defined by an action (GO or NOGO), a recommended speed (0, current speed or maximum speed) and a failure flag in case of irrelevant or missing data. An overview of the TLA is shown in Figure 27.

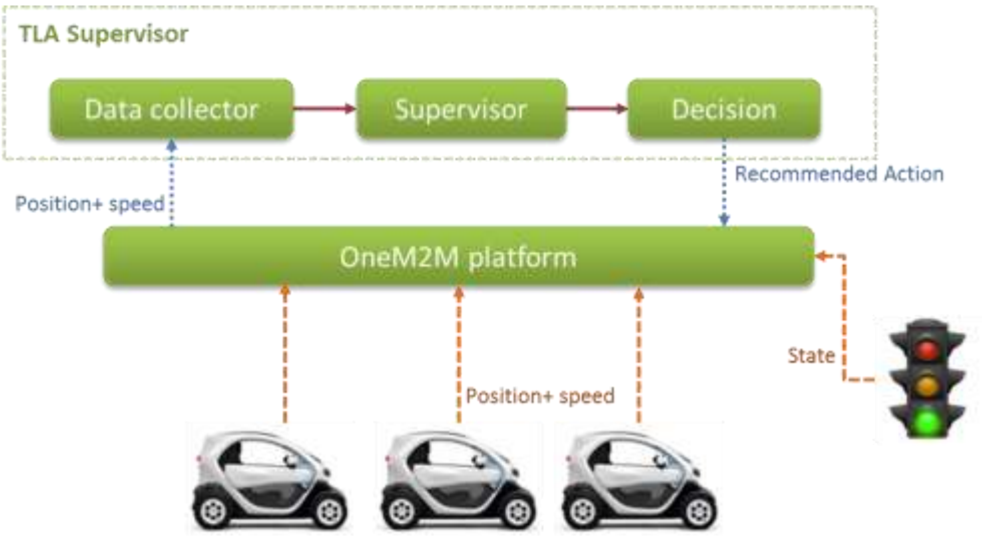


Figure 27 - Traffic Light Assist

3.2.2.4 Hypotheses on IoT impact

- IoT enables integration of platooning in a rebalancing service concept where
  - The vehicles successfully follow the lead vehicle
  - The inter-vehicle distance is respected in order to ensure the security of the platooning
- IoT allows a better anticipation on legacy traffic evolution, most notably on traffic lights status

3.2.2.5 Suggested Performance Indicators

- Smooth passing of traffic light intersections.
- The convoy can cross the traffic lights crossroad safely and without breaking the convoy / passing a red light.

3.3 Italy – Livorno

The Italian permanent Pilot Site is located in Tuscany encompassing the Florence – Livorno highway together with road access to the Livorno sea port and its urban-like environment as shown in Figure 28. It was used by ETSI/ERTICO in November 2016 for the 5th ITS Cooperative Mobility Services Plugtest™ (1st C-ITS ETSI Plugtest™ with real-world test scenarios) and currently it is used by CNIT, Livorno Port Authority and AVR (the latter on behalf of Regional Government Authorities) for developing research and innovation activities.

The testbed consists of three zones:

- The Livorno – Florence freeway: The Livorno – Florence is a highway also known as FI-PI-LI. Renowned as one of the most important arteries and heart to the Tuscany road system, it comprises 31 junctions connecting some of the biggest economic and civil conglomerates of the region like Firenze, Pisa and Livorno, but also Empoli and Pontedera. Highway with dual carriage on a length of 100 km, and two lanes per direction. It is of high value on the territory and well regarded by the public administration. The Livorno – Florence highway is provided with ITS technology for control and data analysis in real time, with 44 VMS spanning over the whole length of the road system and 32 Full-HD cameras.

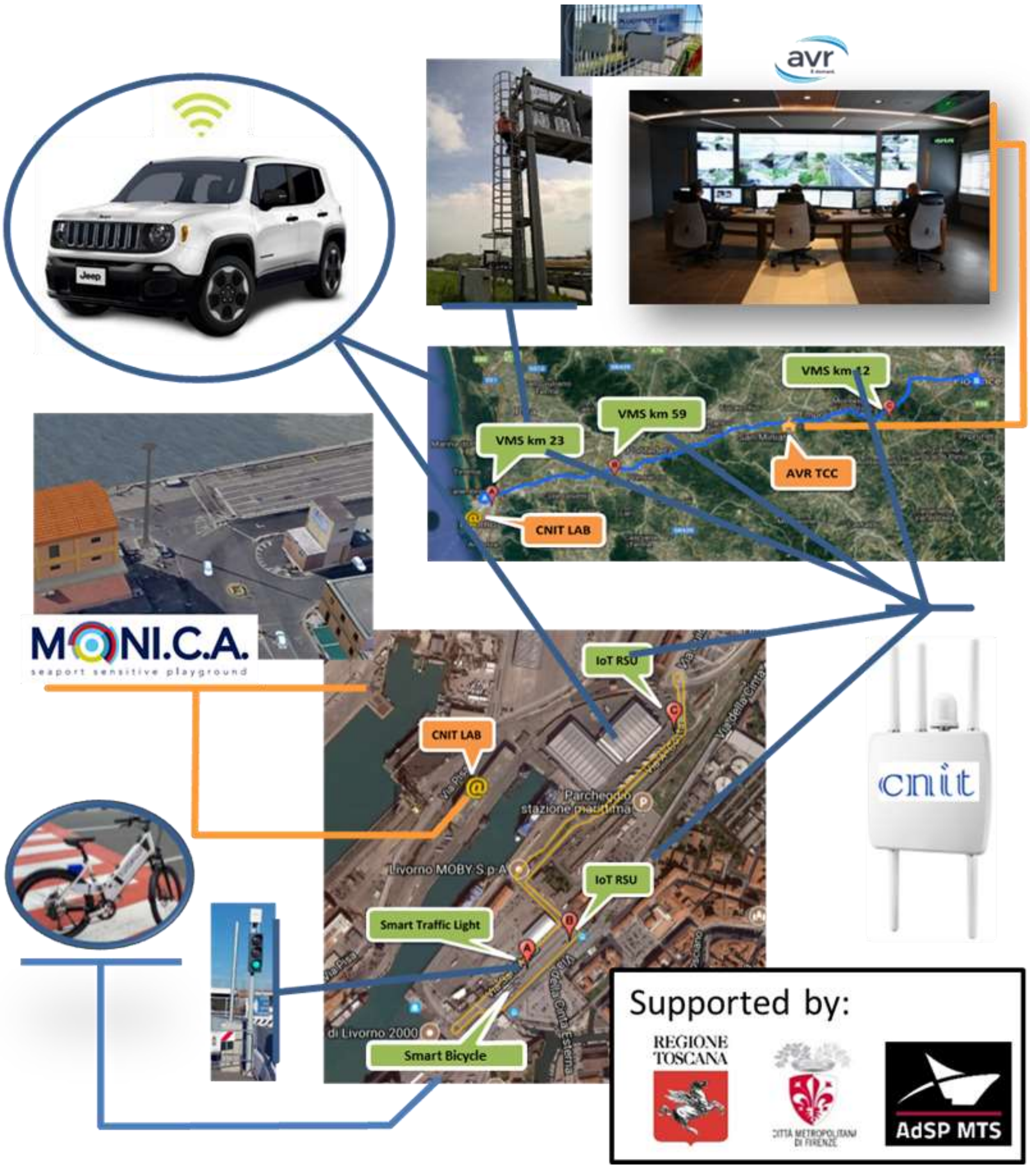


Figure 28: Livorno Permanent Pilot test site and equipment.

- The TCC in Empoli: The Traffic Control Centre is in Empoli which acts as the centre of information and data analysis for the whole system. Built with the latest technologies, it follows the best practices with a state-of-the-art system. A monitor wall follows the development of the traffic from point Firenze to point Livorno and Pisa and vice versa, enabling real time monitoring by the staff of the TCC. Several ITS elements are used to keep track of the events and change the VMS according to the needs of the users and road system.
- The port landside: The test track in the harbour is just in front of the cruise terminal. It is equipped with several service points providing electric sockets and Ethernet connectivity that can be used for a quick setup of testing equipment on the field. Full Wi-Fi coverage of the installation points is provided by means of high-power integrated antennas with Gigabit Ethernet ports. The Internet connectivity is managed by CNIT (and turned on when needed) with proper QoS for the intended use. In the Seaport, there is also a jointly managed laboratory by CNIT and Port Authority, dedicated to pre-conformance tests of AUTOPILOT equipment. Outside the lab there is a permanent installation of an ITS System (RSU and a

smart camera network) communicating by IEEE 802.11 OCB, ETSI ITS-G5, 6LoWPAN, 3GPP and Wi-Fi protocols, for parking lot monitoring.

The vehicle models used in the Italian AUTOPILOT test site are FCA Jeep Renegade with different functions and roles: two vehicles by CRF with automated driving functions and five service vans (2 by CRF, 3 by AVR) with advanced V2X communication capabilities. The latter are used for tuning and pre-testing the systems and the services for the vehicles in the IoT enhanced ITS environment, whereas the former ones are used to demonstrate the performance of the IoT-ITS ecosystems when the automated driving scenarios beyond SAE 3 levels are running. The seaport segment of the test track is shown in Figure 29.

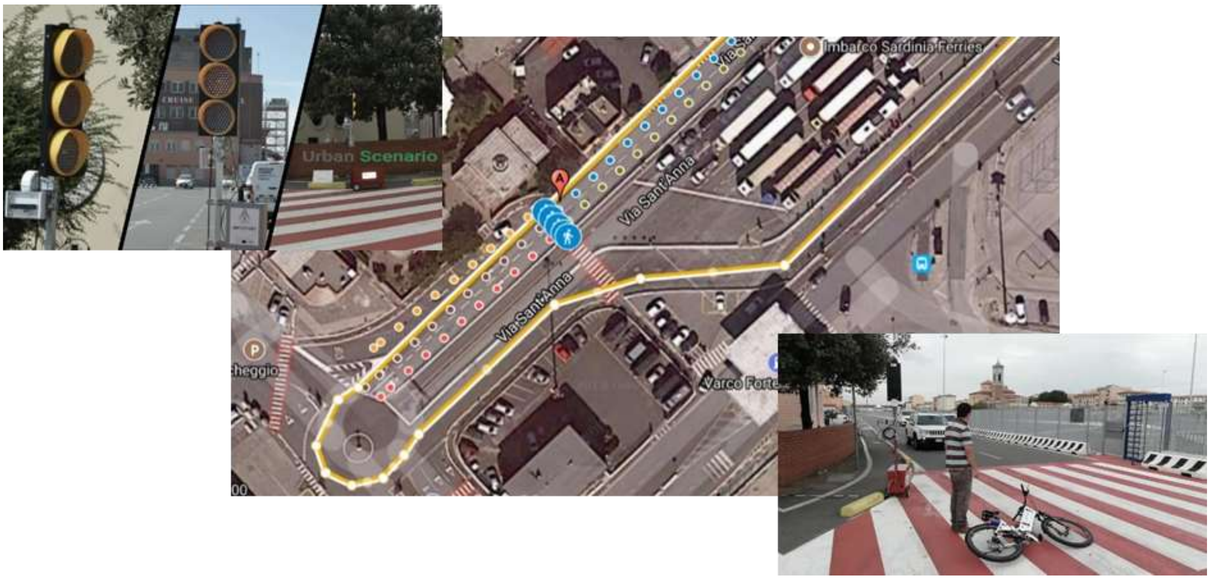


Figure 29: Livorno Seaport segment of the test track, with location (A) for the "smart" traffic light.

The goal of the piloting at the Italian PS was to assess and demonstrate the performance of use cases involving cars with IoT enhanced AD functions, besides other important actors, such as connected cars, VRUs and Traffic/Port Control Centres. The use cases in turn refer to services built on top of them, aiming to gain strong interest from the rising IoT centric society.

To easily explain the different use cases, it is useful to think of them as if they were episodes of a "car-pooling" story (see Figure 30). An AD car is picked up by a user leaving from Florence to take a ferry in Livorno Sea Port; the trip is shared with another passenger, picked up later. During the journey the AD car faces road hazards both on the highway, such as puddles, road works, potholes, etc. and on the urban-like environment of the harbour (pedestrian at crossroads, cyclists, etc.) that are properly detected/communicated to the car using IoT tools. Then the driving style of the car is automatically adapted to mitigate the risk of accidents due to road hazards. Moreover, the data originated by IoT sensors and devices, put in the car and along the road, are collected by an IoT platform for collection of data to be consumed by other entities, such as Traffic Control Centre or Port Monitoring Centre, which can improve the management of the infrastructure, the risk assessment and the infotainment applications.

It is worth noting that, for the Italian PS, the "car-pooling" use case is considered only as a "plot device" and was not included in the real piloting.

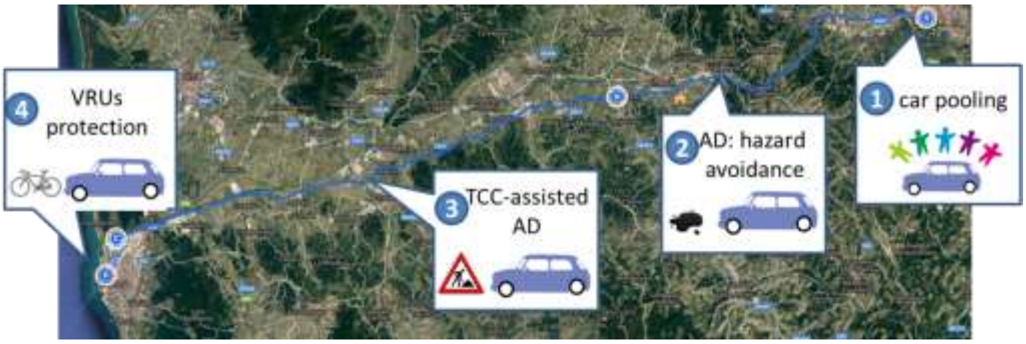


Figure 30: Storyboard of the experimentation at Livorno Pilot Site.

The use cases, applications and services demonstrated in Livorno PS are showed in the following sections.

3.3.1 Use Case 1: Highway Piloting

The scope of these tests involves cars with IoT-enhanced AD functions, driving in a "smart" highway. The cars are Jeep Renegades with on-board equipment, the so-called IoT open vehicular platform, enabling IoT-triggered AD functions: speed adaptation, lane change, lane keeping. Some cars have special sensors also, such as the IoT based pothole detector. The "smart" highway is a freeway where a pervasive IoT ICT system is deployed based on a network of roadside sensors or other sources, capable of collecting information and making it available to cloud-based applications. Connected cars and the traffic control centre have an important role. For safety reasons, connected cars drive in a convoy, following the AD car. The goal is to show how the combined use of IoT and C-ITS can mitigate the risk of accident for an AD car when hazards occur on the road. Here, we deal with two types of hazards: (1) puddles and (2) road works.

3.3.1.1 Storyboard

A driver travels with an AD car from Florence to the Livorno harbour to embark on a ferry. The road travelled during the journey is a "smart highway", notably the FI-PI-LI freeway with IoT sensors and road side equipment capable to trigger hazard warnings to the Traffic Control Centre and to the connected vehicles. The driver enables two AD functions: speed adaptation with lane keeping and lane change. The Driver Assistant on the car is supported by the Internet of Things (IoT). Before entering the critical zones, the AD car receives detailed hazard warnings from the services enabled by the IoT. Thus, the electronic controls of the AD car can perform the manoeuvre appropriate to the situation. This use case can be divided in sub use cases: Road Hazard Warning (puddle), Road Works Warning.

3.3.1.2 Description specifying AD driving mode, services and applications

IoT assisted speed adaptation due to puddle on the road

The goal is to show how the combined use of IoT and C-ITS can mitigate the risk of accident for an AD car, when at a certain point the road becomes dangerous because of a large flooded area. IoT sensors placed along the highway monitor continuously the presence of puddles (see Figure 31). When the hazard is detected, the sensors send an alert to the RSU with detailed information, using IoT standard protocols. RSU broadcasts the info to vehicles (DENM) and to the Traffic Control Centre (TCC). The TCC validates the alert and forwards the DENM message to farther away RSUs. At the same time, the TCC feeds the ETSI oneM2M platform with alert related data. Then the information is consumed by the Connected eHorizon (CeH) application from CONTINENTAL, transmitted to FCA cloud as a modified dynamic speed limit that considers the generated dynamic event. FCA cloud immediately notifies the AD vehicles of the updated information for CeH devices installed on prototypes, and the in-vehicle application feeds the appropriate autonomous functions that perform the necessary adaptation of the driving style in a "smooth" way in combination with information obtained from DENM. A notification/warning through the in-vehicle HMI is generated.

Combination of "Long range" information provided by IoT and related cloud, and "Short range" information provided by ETSI ITS-G5 notification, is expected to enhance capability of an AD vehicle to perform manoeuvres with a more relaxed time response.

In this use cases the RSUs are collocated on the highway gantries, thus CeH can associate speed limits to real point of notification. FCA cloud receives information about recommended speed for the AD car and modifies the driving style (AD speed adaptation) according to the situation. The AD car user is informed of the situation by the HMI, the TCC validate and forward the information towards both the oneM2M platform and the C-ITS network.

The AD car OBU can instantiate both smooth speed adaptation (IoT-enabled speed adaptation for AD car) and eventually C-ITS triggers an emergency warning through in-vehicle HMI.

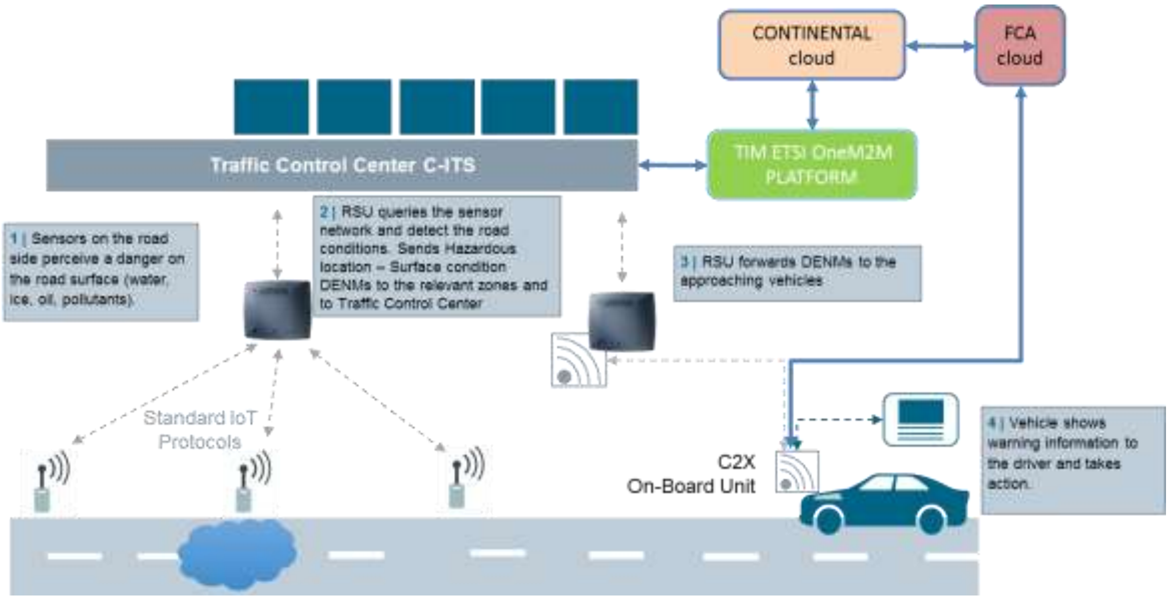


Figure 31: Implementation of "IoT assisted speed adaptation due to puddle on the road" application.

IoT assisted speed adaptation and lane change approaching roadworks

A roadworks event is planned by traffic/road operator and a temporary speed limit is associated with the event. The AD vehicle must reduce its speed approaching the roadworks area, performing a lane change, travelling at the temporary speed limitation and increasing the speed again at the end of the roadwork area. As shown in Figure 32, a stretch of road has some lanes closed to the traffic because of works. The roadworks event was planned by traffic/road operator and a temporary speed limit is associated with the event. The AD vehicle has to reduce its speed approaching the roadworks area, performing a lane change, travelling at the temporary speed limitation and increasing again the speed at the end of the roadwork area.

The application is implemented step by step as follows (see also Figure 32):

1. AD car with C-eHorizon and V2X OBU devices on board travels on the highway. The highway is equipped with IoT G5 RSUs. All the devices publish and share the information by the oneM2M platform in the cloud;

2. The Traffic Control Centre publishes the presence of roadway works to the oneM2M platform;

3. The RSU (subscribed to the oneM2M platform) receives the information and it broadcasts to the vehicles the DENM message containing information about available lanes, speed limits, geometry, alternative routes etc.;

4. At the same time the CONTINENTAL cloud is subscribed to the oneM2M platform; it receives and shares with the FCA cloud the information of the road works, updating dynamically the maps of the Connected e-Horizon installed on-board the CRF AD car;

5. The in-vehicle application fusing the information from the OBU, the C-eHorizon and on-board sensors, performs speed adaptation and lane change manoeuvres.

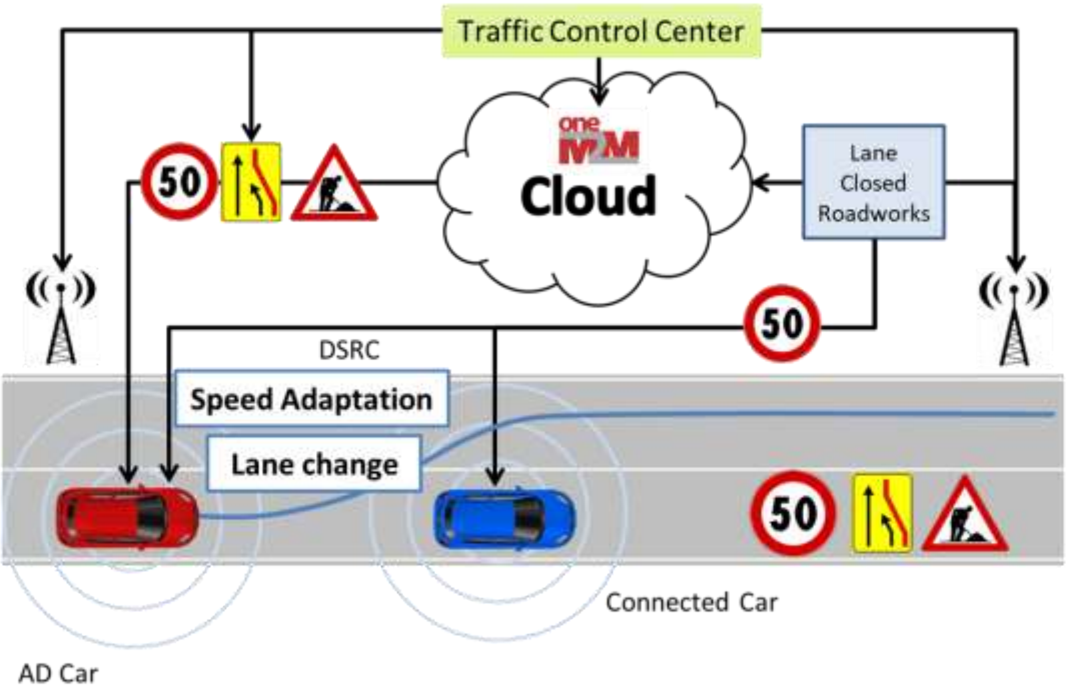


Figure 32: Implementation of "IoT assisted speed adaptation and lane change approaching roadworks" application.

3.3.1.3 IoT utilization

The IoT ITS ecosystem in Livorno PS is a combination of devices, networks, platforms and applications integrated in a standard architecture, as shown in Figure 33. Many devices have been ad hoc developed and integrated in the use cases, considering latency, availability, communication range. The device collection includes: puddle IoT sensors (based on 6LowPAN and NB-IoT technologies), pothole detector, smart trailer (announcing roadway works), roadside units, on board units. All the devices publish data to the oneM2M platform, which are shared and consumed by the applications that have distributed logic into the car, the road side infrastructure, the Traffic Control Centre.

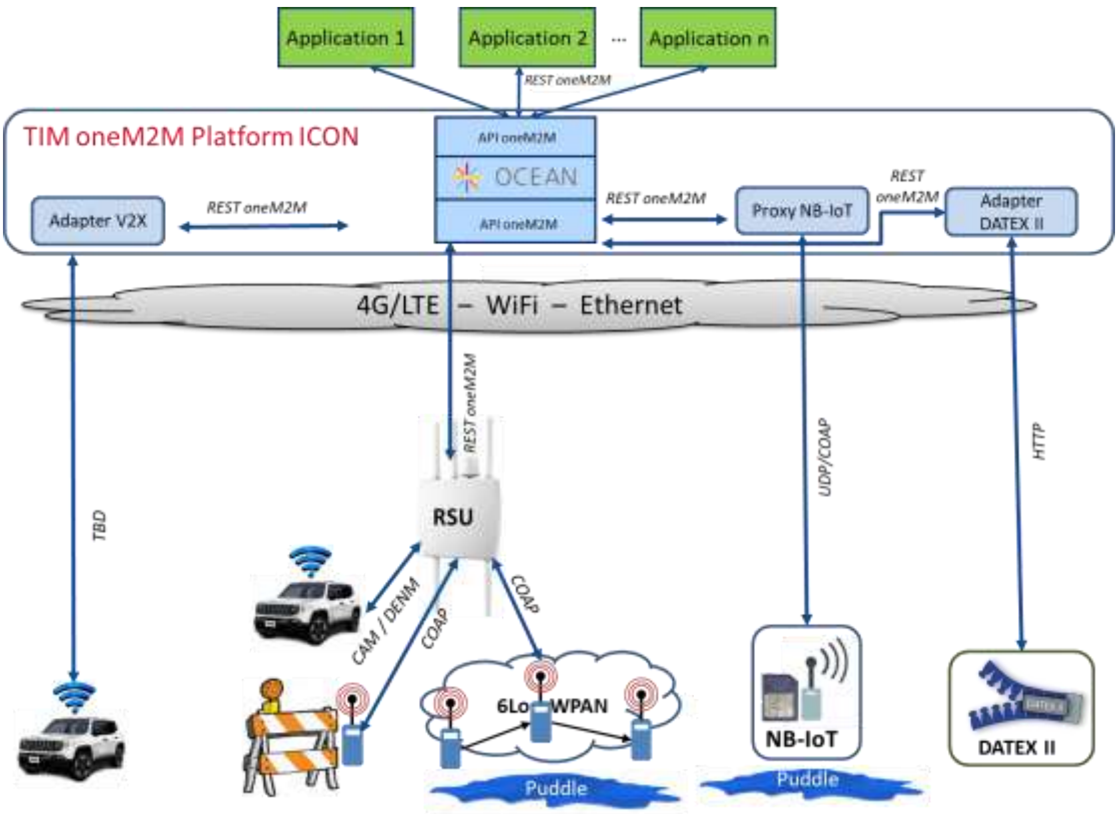


Figure 33: IoT utilization for the Highway Piloting use case at Livorno PS.

3.3.1.4 Hypotheses on IoT impact

How the AD functions interact with different IoT input:

- from oneM2M platform (temporary speed limit due to hazards);
- from I2V (DENM, hazard position and extension);
- from V2V (CAM with info from other vehicles).

With the IoT data, the vehicle should improve the accuracy of anticipating the hazard and enable a smoother driving experience.

The effect of different real traffic conditions (DATEX II) and different IoT communication technologies (NB-IoT vs 6LoWPAN) are considered in the experimentation.

3.3.1.5 Suggested Performance indicators

In this chapter performance indicators are suggested to measure the impact of IoT on Automated Driving. The performance indicators were retrieved from an expert assessment:

- Detection rate: the detection of the road hazard by the vehicle is the capability of receiving and understanding the message triggered by the roadside sensors. Thus, the detection rate measurement has to be intended as the number of times that the hazard message is acknowledged by the vehicle on the total test runs.
- Detection reliability: is the capability of the car to acknowledge the hazard message before entering the hazard zone. This can be measured respective to sensor communication technology changes (6LoWPAN or NB-IoT) and vehicle application changes (DSRC via OBU IoT-platform or CeH).

- Validation latency: is the duration between first occurrence of detection of the hazard by the sensors and the acknowledgement of the validated hazard warning by the vehicles. Tests are performed measuring the time between the instant of time in which the puddle conditions are detected by the sensors and the instant of time in which the information is acknowledged by the car. During this time interval the validation by the TCC operator is also considered. The time stamps of each step travelled by the information are available on the oneM2M platform.
- AD/Driver response performance: vehicle speed within the area affected by the hazard should be constant or slowly varying around the suggested speed, in case of no other vehicles being in front of the AD vehicle. (If there is a vehicle in front, the AD vehicle has to manage its speed in order to consider a safety distance). Outside the area affected by the hazard, the AD vehicle has to drive according to traffic condition, speed limit, target speed set by driver. Hazard information has to be shown in a timely manner on the HMI.
- Smoothness in longitudinal and lateral manoeuvres: In order to evaluate the smoothness in longitudinal manoeuvres, the parameter that we consider is the acceleration. To guarantee a high level of comfort and safety, crossing the hazards, the acceleration value has to be in between -2m/s^2 and +2m/s^2.
- Occurrence of emergency response: In case of emergency response, the form for safety intervention will be filled according to the protocols specified by D3.6.

3.3.1.6 Sustainability of the pilot site and functionalities developed after the project

The functionalities developed for this use case are currently used for conformance and interoperability tests on request of the interested companies or research institutions. The IoT infrastructure in terms of communication network, platforms and applications is permanently up and running. The public authorities Tuscany Region Government and Florence Metropolitan City are supporting the request of Livorno PS to the Italian government to extend the experimentation scope for AD cars, according to the “Smart Road” decree. Furthermore, the Livorno pilot site presented its candidature to ETSI for hosting the next C-V2X plugtest.

3.3.2 Use Case 2: Urban driving

This use case demonstrates how IoT may impact the safety of VRUs in an urban-like scenario (instantiated at a harbour settlement) with AD cars, connected cars, pedestrians at a traffic light crossing, connected bicycles, and a seaport monitoring centre. IoT can provide redundant information that can be fused with other sensors’ data in order to produce a robust and reliable description of the surrounding environment. In some cases, IoT information is not detectable from common sensing devices, e.g. the remaining time before the traffic light phase change and in some other cases IoT can provide information in advance with respect other devices, for preventively acting on the vehicle dynamics, avoiding or mitigating crashes and increasing safety.

3.3.2.1 Storyboard

An AD car is travelling to embark on a ferry. On arrival in Livorno, it exits from the highway and gets into the public road inside the harbour landside. That area is a managed public road with "smart traffic light", roadside equipment and a Port Monitoring System capable to provide information that are not detectable by on board sensors, notably the remaining time to traffic light phase change and also other useful information about VRU behaviour and presence of crowd at cross road.

The speed adaptation AD function is enabled. The Driver Assistant on the car is supported by the IoT.

Before approaching the traffic light, the AD car receives detailed information about the situation at the intersection: phase and remaining time before the phase change, traffic status, VRU presence and behaviour, jaywalking, etc. Thus, the electronic controls of the AD Car can perform the manoeuvre appropriate to the situation.

This use case has the following scenarios: Speed adaptation approaching an intersection regulated by traffic light, speed adaptation at jaywalking occurrence, speed adaptation with a fallen bicyclist, speed adaptation when potholes are detected.

3.3.2.2 Description specifying AD driving mode, services and applications

The service "VRU protection" implemented by IoT in the urban driving scenario offers an overall increased safety for both VRUs and cars. This service raised the interest of insurance companies that have been actively involved as stakeholders during the business impact evaluation workshops. It has been tested in the following situations.

Speed adaptation approaching an intersection regulated by traffic light

A "smart" traffic light sends SPaT and MAP messages describing the topology, actual status of the traffic light to other connected vehicles and to the oneM2M platform on the cloud (see Figure 34). An AD vehicle consumes the information and autonomously adapts its speed in order to cross the intersection without violating the traffic light phases, considering also other vehicles moving in front.

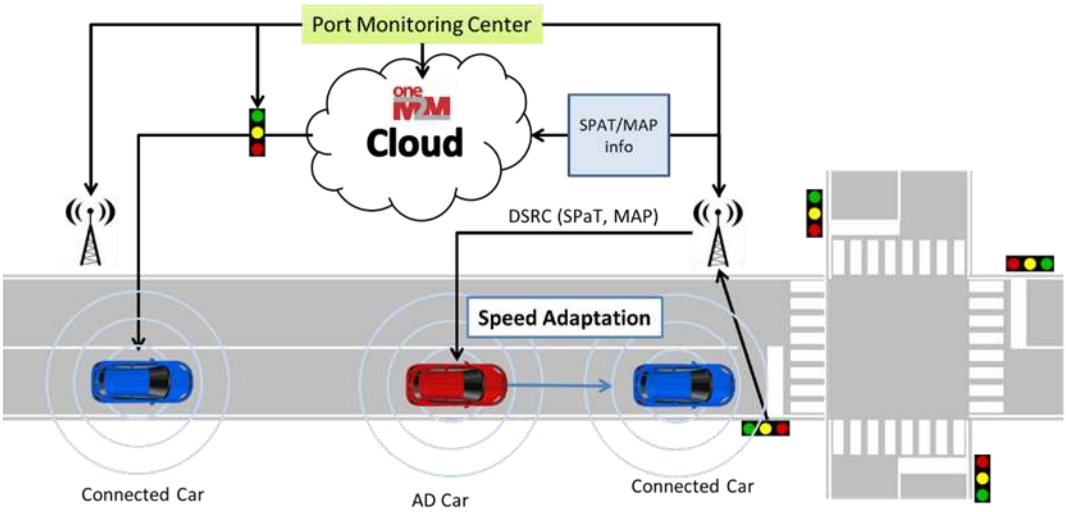


Figure 34: Implementation of "speed adaptation at traffic light" application.

Speed adaptation with traffic light violation by pedestrians

A "smart" traffic light with an RSU and a stereo camera sends SPaT and MAP messages describing the topology, actual status of the traffic light, presence of pedestrians, and jaywalking occurrence to other connected vehicles and to the oneM2M platform on the cloud. An AD vehicle consumes the information and autonomously adapts its speed in order to cross the intersection without violating the traffic light phases, or even stop to avoid collision with pedestrian. The influence of other vehicles moving in front is considered too. Moreover, the detection of VRUs and the traffic light status is displayed on the HMI in the AD car.

The information from RSUs and OBUs is also sent to the IoT data platform via IoT standard protocols and it can then be processed by the Port Monitoring Centre for real time risk assessment and safety services.

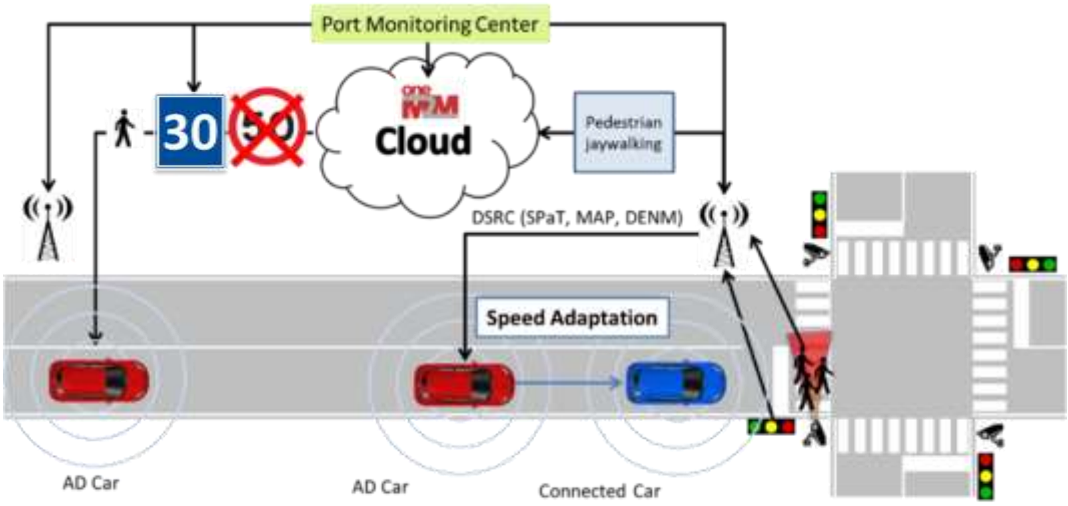
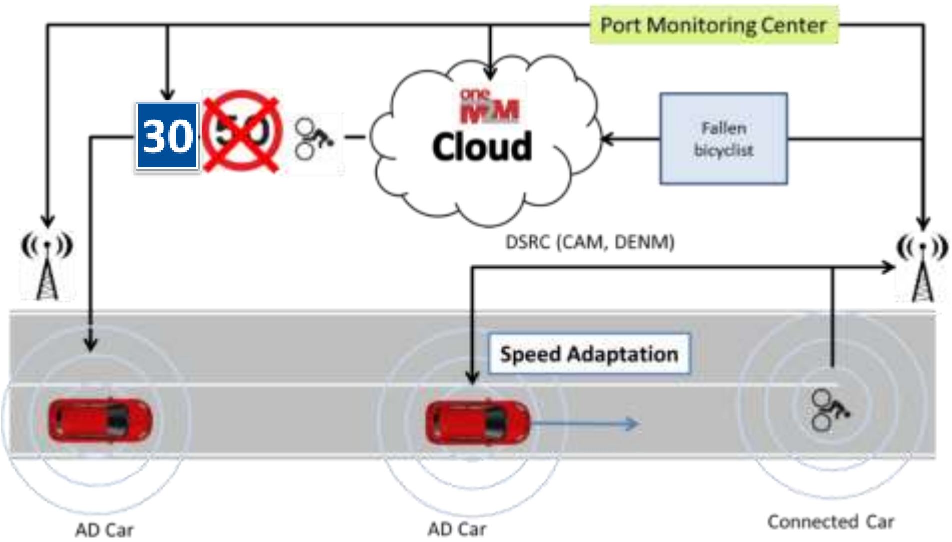


Figure 35: Implementation of "speed adaptation with traffic light violation by pedestrians" application.

Speed adaptation with a fallen bicyclist

An AD vehicle is moving in an urban scenario and other road users, including connected bicycles, notify their presence to the AD vehicle; at a certain point, a bicyclist falls down while the AD is moving towards the accident zone (see Figure 36). The AD vehicle, informed by IoT of the dangerous situation, smoothly decreases its speed and stops before reaching the accident area. The information is also sent to the oneM2M platform and can be retrieved by other vehicles in the same area via the cloud. The oneM2M notifies also the MONICA cloud that displays the scene from a virtual 3D camera and can change the advisory speed in the relevant area to avoid possible



problems.

Figure 36: Implementation of "speed adaptation with a fallen bicyclist" application.

Speed adaptation with pothole detection

The goal of this use case is to demonstrate how additional IoT sensors placed in the AUTOPILOT prototype are enhancing the functions of the car itself. In such a way, the vehicle can be used for example as an IoT sensor for detecting the surface condition for both highway and urban scenarios.

As shown in Figure 37 , the cars detect a pothole using the combination of one or more of the following sensors: smartphone, 6LoWPAN vibration sensor, and IMU. The information is sent to the cloud and can be sent back to other connected vehicles for warning. The information is also transmitted via V2V to AD cars that can automatically adapt the speed.

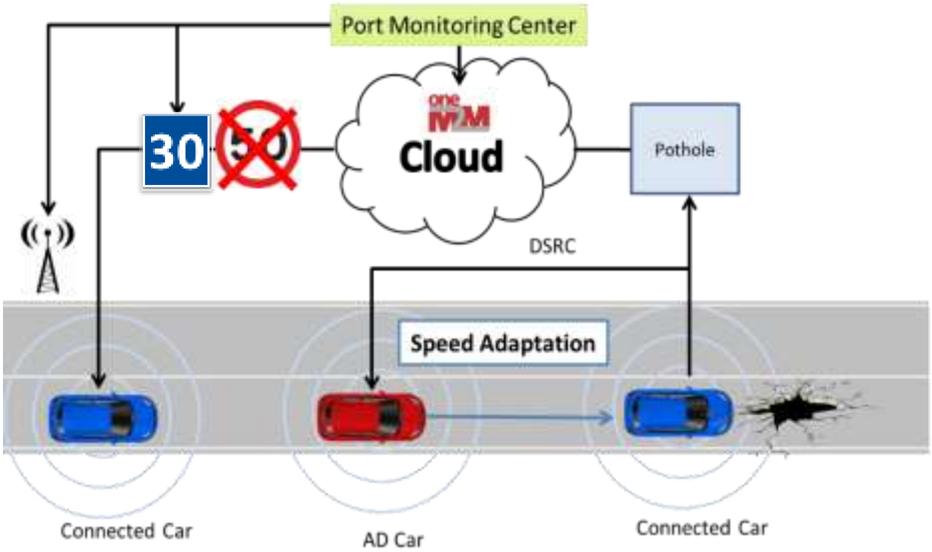


Figure 37: Implementation of "speed adaptation with pothole detection" application.

3.3.2.3 IoT Utilization

In the urban scenario the smart traffic light by LINKS is connected to the Internet via the Wi-Fi backbone of the test trial, this device publishes data about the status of the crossroad to the oneM2M platform. Two additional RSUs placed along the test track gather the CAM messages from the vehicles and publish the content to the oneM2M platform via LTE cellular network. Also, the vehicles and the bicycle publish messages to the oneM2M platform according to the DMAG data model. The 3D Port Monitoring application processes the data to display real time the scene and provides information to the users (cars and VRUs) approaching the cross road (see Figure 38).

Figure 38: Jaywalking scenario displayed in real-time by the Port Monitoring Center App.

The list of the IoT utilization follows:

- IoT information is used to assist the speed adaptation of the AD car and improving safety at the crossroad.
- Traffic lights status is sent through IoT to the vehicle.
- Infrastructure camera detects jaywalking and sends this information to the vehicle through IoT.

- In case of a fall the connected bicycle sends warning to the vehicle through IoT.
- IoT provides information to the Port Monitoring Center that displays the scene in real-time with a virtual camera.

3.3.2.4 Hypotheses on IoT Impact

The impact of IoT on the urban driving use case can be assessed by means of the following hypotheses:

- IoT will enhance the environment detections
- IoT will enhance the VRUs detections
- IoT will enable safety applications for VRUs and AD cars
- IoT will enhance the management of the port operations at ferry terminal boarding area

3.3.2.5 Suggested Performance indicators

The following performance indicators are suggested to measure the impact of IoT on Automated Driving:

- Detection rate: the detection of the cross-road status by the vehicle is the capability of receiving and understanding the message triggered by the smart traffic light. Thus, the detection rate measurement has to be intended as the number of times that the warning message is acknowledged by the vehicle on the total test runs.
- Detection reliability: is the capability of the car to acknowledge the warning message in time for implementing the actuation. This can be measured respect to the different scenarios: traffic light phase, jaywalking, fallen bicycle, pothole.
- Validation latency: is the duration between first occurrence of detection of the hazard by the sensors and the acknowledgement of the validated hazard warning by the vehicles. Tests are performed measuring the time between the instant of time in which the hazard conditions are detected by the sensors and the instant of time in which the information is acknowledged by the car.
- AD/Driver response performance: vehicle speed inside the area affected by the hazard should be constant or slowly varying around the suggested speed, in case of no other vehicles being in front of the AD vehicle. (If there is a vehicle in front, the AD vehicle has to manage its speed in order to consider a safety distance). Outside the area affected by the hazard the AD vehicle has to drive according to traffic condition, speed limit, target speed set by driver. Hazard information has to be timely shown on the HMI.
- Occurrence of emergency response: In case of emergency response, the form for safety intervention will be filled according to the protocols specified by D3.6.

3.3.2.6 Sustainability of the pilot site and functionalities developed after the project

The functionalities developed for this use case are currently used for conformance and interoperability tests on request of the interested companies or research institutions. The IoT infrastructure in terms of communication network, platforms and applications is permanently up and running. The public authorities Tuscany Region Government and Port Authority are supporting the request of Livorno PS to the Italian government to extend the experimentation scope for AD cars, according to the “Smart Road” decree. Furthermore, the Livorno pilot site presented its candidature to ETSI for hosting the next C-V2X plugtest.

3.4 Netherlands – Brainport

The Brainport Pilot site concerns the region of Helmond-Eindhoven in the Netherlands, as depicted in Figure 39. The region includes 3 campuses (Eindhoven University, Automotive Campus, High-Tech Campus) and Eindhoven airport. The main road between the cities of Eindhoven and Helmond is the A270 motorway, which is part of the DITCM (Dutch Integrated Testsite Cooperative Mobility) test site.

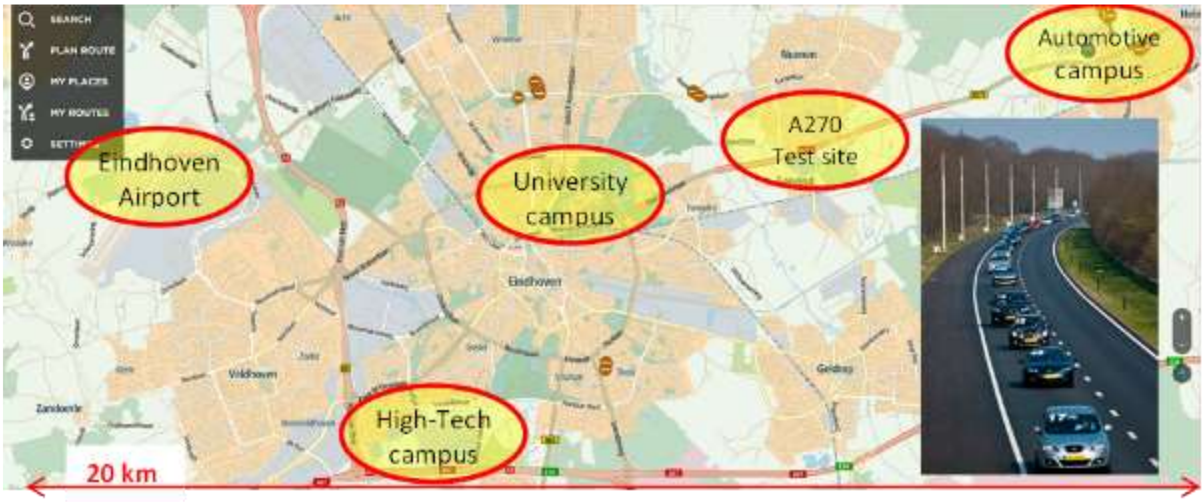


Figure 39: Brainport Pilot site.

This DITCM test site is a purpose-built facility for the development, testing and validation of Intelligent Transport Systems (ITS) and cooperative driving technologies. It consists of both a motorway and urban environments. The DITCM test site is 8 km long, with 6 km of motorway. Roadside equipment is responsible for vehicle detection and V2X communication. All other equipment is placed indoor and includes sensor fusion facilities, application platforms and a traffic management centre. The test site is connected to neighbouring urban sections and other information sources via a high-speed internet connection. In addition to the DITCM control room the Traffic Innovation Centre is also located on the Automotive Campus.

On this Brainport Pilot site various use cases, i.e. Automated Driving modes and associated user level and AD vehicle level services, have been developed:

1. **Platooning** from Helmond to Eindhoven on the A270 motorway (2 x 2 lanes). It was already equipped with ITS-G5 communication and traffic monitoring cameras to a great extent. The speed limit is 100 km/h.
2. **Driverless car rebalancing** deployed locally on the Eindhoven University campus. The University Campus has a 2-km road network and a 30 km/h speed limit. On the campus, there are neither cross walks nor traffic lights.
3. **Automated Valet Parking** (AVP) implemented on the Automotive campus. The Campus has a parking lot which can host 200 vehicles, and several access roads. The speed limit is 15 km/h.
4. The **Highway Pilot** targeting the A270 motorway but actually deployed on the Campus due to the (too) good road conditions of the motorway.

A ride sharing service serves in Brainport as an umbrella service and portal on the user level. It is able to interact with some of the aforementioned use cases (Platooning and AVP). This umbrella service referred to as mobility service, developed and demonstrated at the ITS Europe Congress but not piloted, is described separately in Section 3.4.5.

3.4.1 Use Case 1: Platooning

The mapping of AD driving modes, services and applications developed in this use case to Chapter 2 is listed below, with two remarks:

Table 4: Mapping of use-case to AD modes, services, and applications listed in Chapter 2.

Automated driving modes	Services	Applications
Platooning	None	Driving Route optimisation

Remark 1: None of the services listed in Chapter 2 has been applied in this use case. Other services instead have been considered relevant and were developed to complete the concept and provide the user the associated experience.

Remark 2: Automated Driving Route Optimization is in this use case applied during the platoon formation process during which Automated Driving does not yet take place. The way we used this functionality is rather like a service which is offered to the drivers of the vehicles. Hence, it is described here as "Driving Route Optimisation".

3.4.1.1 Storyboard

The story in which the platooning use case is embedded is about a person Wendy who works at TNO at the Automotive Campus and wants to travel to Eindhoven university as efficient as possible (travel time, comfort, fuel consumption) and would like to use automated driving to do some work in the car. The idea is that a mobility service arranges his trip and interacts with other advanced services related to AD vehicles such as Automated Valet Parking (AVP), Platooning or a Car/Ride Sharing service. In the story, there is another person Bart who is also interested to engage in a platoon as a leader (based on specific incentives).

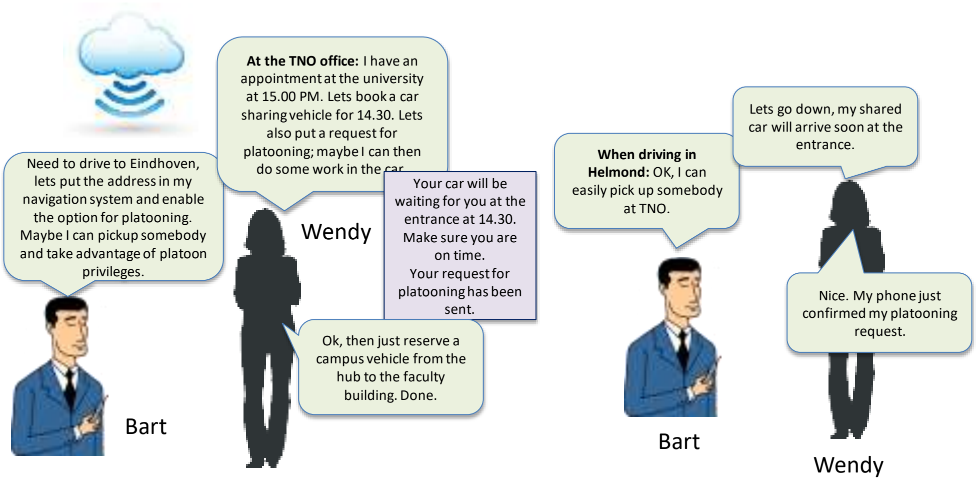


Figure 40: Storyboard for Platooning (part of a broader service concept)

However, in this broader description, the platooning functionality and associated services is highlighted. The Platooning use case is depicted schematically in Figure 40.

Figure 41: Overview of the platooning use case (formation part is not illustrated).

Wendy plans her trip to Eindhoven using the umbrella mobility service. This service has reserved a car sharing vehicle for her that will be driven to the drop-off/collect point in front of the TNO office building at a planned time. The umbrella mobility service ensures that Wendy can get into the vehicle at the agreed time for a trip from Helmond to Eindhoven. In order to join a platoon, a match is sought and found with another user (Bart in our story) who had made clear earlier in time that he is willing to act as leader of any platoon if requested as he can look forward to some benefits like using the priority lane. For this purpose, he shares his personal travel intentions with the umbrella mobility service. So, a match is made, and Bart's vehicle is identified as platoon leader and he will be travelling through Helmond in the direction of Eindhoven. Both platooning candidates are given personal route planning and speed advice to bring their vehicles together. So, in the considered use case, Wendy starts from a standstill and Bart keeps driving on the main road towards the motorway. A traffic light to enter the main road from the Campus plays a role in assuring a suitable timing window for the formation process. The formation is supposed to take place successfully on the N270 or at the beginning of the A270 highway, after which the platoon will drive the common part of the route over the highway until the point where Bart and Wendy need to break up because they need to go separate ways. Before that moment, Wendy is requested to take over the driving task. Finally, Bart and Wendy both continue their journey. Wendy will drive to the university campus where she will continue travelling using the driverless car rebalancing service.

Bart and Wendy are approaching the A270 highway under guidance of the Platoon Service which provides them real-time route and speed advice to enable to arrive at the predicted rendezvous point. The Platoon Service itself gets the route advice from an external cloud service using Floating Car data and calculates the speed advice based on data it gets from the cloud-based Traffic Management Service. While in formation, Bart and Wendy will continue to receive route and speed advice (see HMI screen below) until both their vehicles closed in on each other sufficiently for the V2V link to be activated in order to form the actual platoon. Next, platooning is enabled, meaning that the vehicle(s) have automated steering and headway control with respect to the platoon leader.

3.4.1.2 Description specifying AD driving mode, services and applications

If we ignore the functionality of the umbrella mobility service in this section, the core of the use case functionality is the platooning driving mode which is enriched by user and AD vehicle-oriented services. In addition, we adjusted the *World Model based target tracking application* to allow for the addition of world model data obtained from external sources. Most services developed utilize IoT and long-range communications. In the following sections, these functionalities are described.

Automated Driving mode: Platooning

The platooning driving mode itself which is based on CACC with ITS-G5 for V2V communications has not been modified, except that it can now be monitored and influenced externally via cloud-based vehicle services. Also the HMI which is made available to the drivers is not part of the platooning driving mode as such but is a service we added to this driving mode. The V2V communications has been extended with UWB technology for communication and ranging, but this has not been fully integrated into the CACC application yet.

We adjusted the *Platoon Management application* which resides in both vehicles and manages the CACC process at the operational level (decision making, efficiency improvement etc.). Due to the fact that it is inherently part of the driving mode, the Platoon Management application is addressed here. In the current AUTOPILOT implementation, the Platoon Management application has the following functionalities:

- Interacts with Platooning Service:
  - Receives speed advice (during platooning);
  - Conducts checks on speed advice and adjusts ACC setting accordingly;
  - Reports back its actual position.
- Supports the platoon operation:
  - Regulates inter-vehicle distance, platoon assembly process, coupling and decoupling of vehicles to the platoon, etc.;
  - Listens to the Local Dynamic Map (LDM) Service to receive up-to-date vehicle detection data to be added to the ego vehicle's world model;
  - Adjusts ACC setting to anticipate on slow traffic ahead, based on World Model target tracking.

Services for AD Vehicles: Platooning Service

The *Platooning Service* is a cloud-based service which dwells on the oneM2M IoT platform and interacts with vehicles and their drivers involved in platooning. The Platooning Service operates on two driving task levels (strategical for simple scheduling and planning and tactical for vehicle speed adjustment) and has the following functionalities:

- Arranges platooning vehicles:
  - Handles requests of a car to follow a platoon leader or join an existing platoon;
  - Identifies platoon leader based on timing efficiency for platoon assembly; the idea is that the platoon can be formed while driving.
- Facilitates platoon forming and operation:
  - Provides route and speed advice to platooning vehicles to position them at the proper inter-vehicle distance for V2V communication range;
  - Retrieves data from the Traffic Management Service (symbolizing the road operator's traffic centre about lane specific regulatory information and actual traffic situation (e.g. average lane speed);
  - Provides speed advice to the lead vehicle (change of ACC setpoint). The speed advice takes into account the regulatory speed and the measured average traffic speed both on the relevant lane, and the TLC status of approaching traffic lights.
- Applies discovery of additional services the platoon (and/or individual vehicles) can subscribe to, in this particular case the Local Dynamic Map Service.

HMI Service

An HMI service is developed to fully support the driver. Both drivers are informed in real-time via a web based graphical user interface on a tablet device inside the vehicle, during the formation and platooning stages as depicted in Figure 42. During formation it displays the speed advice and route advice (visualized on a separate map) and it displays the actual status (connecting, forming, assembling, in platoon). It shows lateral control settings and displays vehicle sensor data. It also visualizes any warnings (e.g. slow traffic ahead) which is combined with specific audio signals.

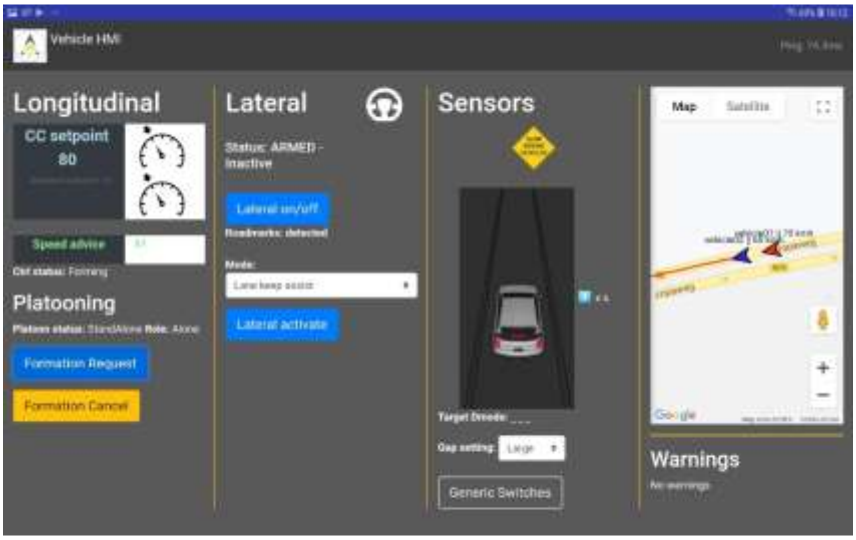


Figure 42: HMI of Bart's car with speed advice indication in green. On the right the relative positions of Bart and Wendy during formations

Local Dynamic Map (LDM) service

An LDM service is developed which publishes in near real-time vehicle detection data locally within its coverage area. This vehicle detection data is received from the cloud-based Traffic Management Service. Due to performance reasons, the LDM service does not dwell on the oneM2M platform. It is a dedicated service which runs on an Edge Computing platform, which is actually very near to the N270/A270. The LDM service can be discovered by the Platoon Service which then provides the lead vehicle of the platoon a pointer (IP-address) in order to subscribe to the LDM service. The lead vehicle receives this data and interprets these as additional virtual targets on top of the targets the vehicle has detected with its own sensors. Hence, these 'virtual targets' will be added to its ego world model. So the functionalities of the LDM service are:

Traffic Management Service

The Traffic Management Service symbolizes the traffic centre providing important road operator services like maximum speed, actual average lane speed, static and dynamic information of junctions and traffic lights, lane status information, etc. The Traffic Management Service developed has the following functionalities:

- Provides vehicle detection data as well as derived parameters such as average lane speed, based on raw data coming from the traffic management centre connected road side units like cameras

- Provides lane specific SPaT and MAP data of relevant crossings and lane specific regulatory maximum speeds from traffic management centre

The TM service is not an end-user service but provides a service to other services.

Auxiliary services and applications

During formation, the routes of both vehicles are continuously recalculated to ensure a successful rendezvous point. This rendezvous point is not static but dynamic. This **driving route optimisation service** is developed to specifically support the formation process and uses third party Floating Car data. The route optimization service not only provides route data but also average speed per route section.

In support of Automated Driving on SAE Level 3/4 we use RTK DGPS service for enhanced positioning and a real-time HD map distribution service for localisation.

World Model based target tracking (ACC setpoint adjustment)

The vehicles in the use case already applied world model-based target tracking to allow the following vehicle to remain aware of the range towards the lead vehicle. This functionality has now been actively used also by the lead vehicle whereby vehicle detections provided by the LDM service are added to the lead vehicle's ego world model. The target tracking algorithm has been adjusted to allow the lead vehicle to detect slow vehicles further downstream which the vehicle would not be able to detect itself with its sensors.

3.4.1.3 IoT Utilization

As already mentioned in Section 2.1.3 the technology typically used for platooning consists of environmental perception using radar and camera sensors, ITS-G5 wireless communication to exchange relevant data via V2X protocols, and automation of acceleration/deceleration and steering.

The platoon relies fully on on-board sensing and traffic interpretation, and platoon management is done on the vehicle level, e.g. vehicles can only join the platoon when the inter vehicle distance is close enough for V2X communication. Current platooning has not reached SAE level 3/4 automation, as the human driver needs to monitor the driving environment and is the fall-back for the driving task at any time. For higher automation levels, amongst other things, the required integrity of sensor information and communication needs to meet challenging standards.

Taking the above into consideration, which describes well the situation at the start of the project, the concept of Internet-of-Things (IoT) is used to obtain and exchange additional and redundant information that can improve situational awareness as well as integrity levels. Below, an overview of the information actually exchanged by IoT is given:

- All information exchange required between platooning service, traffic management service and platooning vehicles
- Publication on IoT platform of position, velocity, planned route, etc. of IoT equipped platooning vehicles from on-board sensors and systems
- Publication on IoT platform of actual positions and velocities of legacy traffic, obtained from roadside camera systems
- Publication on IoT platform of lane specific Traffic lights status
- Information on services which vehicles can subscribe to (IoT platform performs service discovery)

- Information aiming for (redundant) localisation, e.g.:
  - real-time HD maps
  - position error corrections through RTK DGPS service

3.4.1.4 Hypotheses on IoT Impact

Regarding the added value or impact of IoT the following hypotheses for this use case apply:

- IoT will enable integration of platooning in a mobility service concept
- IoT will facilitate finding other vehicles as members for platooning
- IoT will extend the distance at which vehicles initiate towards platooning
- IoT will allow a better anticipation on legacy traffic evolution, traffic lights, etc.
- IoT will contribute to reach a higher level of automation by enhancing safety as result of redundant sensor information

Note that there can also be a negative impact of IoT (e.g. cyber security risks). This is however not explicitly addressed in the development of this use case.

3.4.1.5 Suggested Performance Indicators

- Travel time
- Number of platoon disruptions
- Acceleration/deceleration level of vehicles
- Speed variation
- Ride comfort

3.4.2 Use Case 2: Urban driving with driverless car rebalancing

Table 5: Mapping of use-case to AD modes, services, and applications listed in Chapter 2.

Automated driving modes	Services	Applications
Urban driving (Sec. 2.1.4)	Driverless car rebalancing (Sec. 2.2.2)	6^{th} sense driving (Sec. 2.3.2)

3.4.2.1 Storyboard

An urban driving with driverless car rebalancing use case was developed within the constraints of the TU/e Campus (1 km radius). The targeted service offers driverless rebalancing of several AD vehicles distributed over several pickup points within a car sharing concept. The AD vehicles can drive automatically (speed limit of 10 km/h) between dedicated pickup points on the campus, using pre-defined and 3D-mapped tracks and a 6^{th} sense driving application (sharing VRU and crowd positions via IoT) to improve their world model.

Urban driving with driverless car rebalancing storyboard (see Figure 43):

1. A user requests an AD vehicle using a smartphone app.
2. The smartphone app sends the request to the IoT platform; the driverless rebalancing service selects and sends the AD vehicle to the closest available dedicated pickup point in the campus.

3. 3-5. The unmanned AD vehicle moves through the campus to the designated pickup point, using both its environmental sensors and real-time information from IoT devices (6th sense driving), and using crowd detection information, to choose the correct and safest route.

4. The user receives a confirmation that the AD vehicle will be ready at the designated pickup point at a specific time. The user can then drive the vehicle manually off campus and the IoT platform receives a confirmation of the successful process.

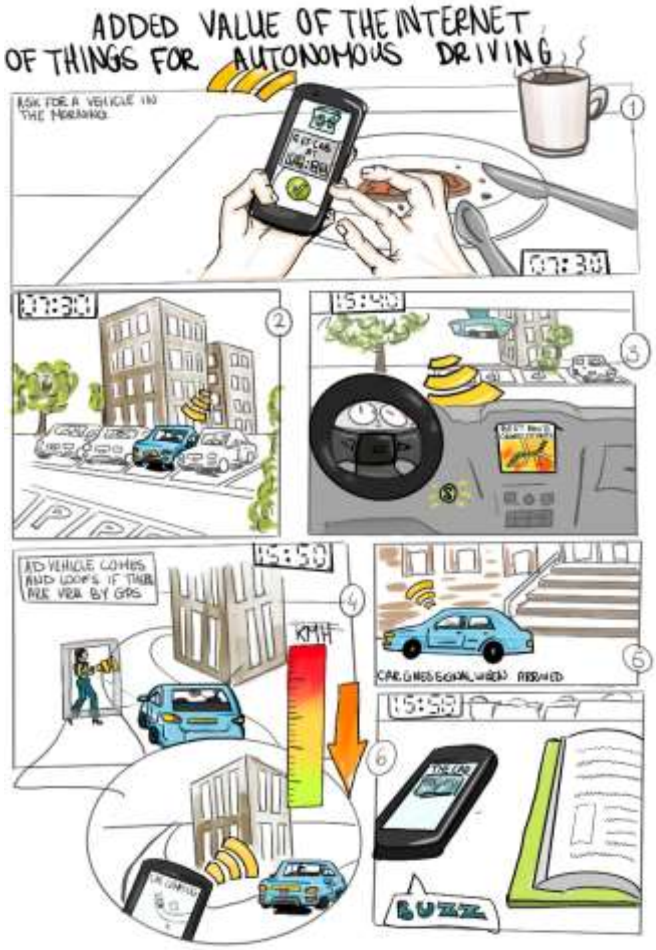


Figure 43: Driverless car rebalancing story board

3.4.2.2 Description specifying AD driving mode, services and applications

The main goal of the urban rebalancing use case is to demonstrate a vehicle driving autonomously within the constraints of TU/e Campus (Urban environment) using both environmental sensor data as well as data available through IoT platform to improve the world model & Local Dynamic Maps embedded in each vehicle (6th sense driving).

Figure 44 shows an overview of possible pickup points on campus and routes the AD vehicle will have to take.

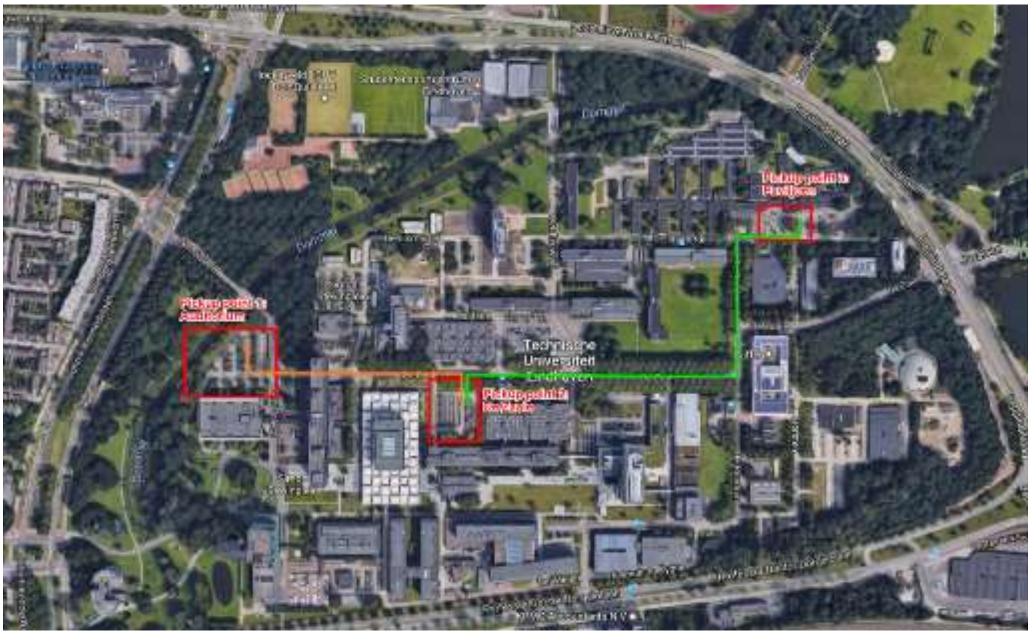


Figure 44: TU/e Campus site with possible pickup point and routes for the urban rebalancing use case.

The complete pilot involving the urban rebalancing use case can be divided into several functional components, as shown in Table 6**.**

Table 6: Functional components.

	IoT platform level (Cloud)		**IoT platform / Vehicle level**	
Functional components	Car Sharing / rebalance service	Crowd Estimation & rerouting	Urban Automated Driving (on campus)	Collaborative Perception / World model
Driverless car rebalancing on TU/e campus	Handling requests and identification	Based on crowd detection, reroutes the vehicle to less crowded area	Automatically drive AD vehicle to requested pickup point	Make use of IoT enabled VRUs for detection and tracking + IoT enabled crowd estimation

Within the constraints of the TU/e campus there are several challenges which encourage the use of IoT devices and IoT platforms to enrich the World Model / Local Dynamic Map of an Automated Driving vehicle:

- There are no lane markings
- There are no pedestrian crossings
- There are no traffic lights or signs
- There are no X2V RSUs
- There are no dedicated cycling paths

This implies that especially VRUs (Vulnerable Road Users: pedestrians & cyclists) will not be walking on the road on dedicated marked places (such as crossings), thus their detection and intended path and behaviour prediction is crucial on this pilot site.

Therefore, next to the above-mentioned functional components, two IoT enabled functionalities are required:

- Access to crowd estimation data to consider the probability of a large amount of VRUs on campus terrain (i.e. When more students are attending lectures, there are less VRUs on the road and the AD vehicle is more likely to safely move from A to B than when a lot of students are walking over campus terrain).
- Smartphone app with localization functionality: VRUs can be tracked using standard phone GPS sensor or Wi-Fi RSSI. This information can be used to feed the world model of an AD vehicle, so it can predict the VRUs path (together with other in-vehicle environmental sensors).

In the AUTOPILOT project, TU/e focused on developing a methodology for creating and maintaining an explicit world model (WM) for the autonomous car that estimates the current world state based on sensor data, models and information from IoT using above mentioned methods.

To achieve this, TU/e focused on mapping and localization using both on-board sensors (cameras, RADARs, etc.) as well as using three IoT enabled data streams.

3.4.2.3 IoT Utilization

Current AD vehicles rely heavily on environmental perception sensors such as cameras, LIDAR & RADAR and vehicle odometry sensors. Data from all these sensors are combined and fused into the world model of the AD vehicle, such that it can predict the path of other road users (and obstacles) and decide which path to take itself.

In current technology, especially algorithms for cameras rely on markers in the world, such as lane markings or traffic signs, to localize the ego vehicle and the detected objects relative to the ego vehicle.

TU/e campus provides an interesting case: there are no lane markings, no traffic signs, no pedestrian crossings, no RSUs and no traffic lights. However, aside from the multiple vehicles, there are a lot of pedestrians and cyclists. This creates a challenging urban environment for Automated Driving vehicles.

The concept of IoT is used here to connect probabilistic & historical data not available yet in AD vehicles for Urban Driving using three different data streams to improve the world model of an AD vehicle:

- Use crowd detection (and lecture schedule) data to adapt probabilistic models in the AD vehicle’s World Model. Statistically predict the probability of large amount of VRUs on the roads. And so, decide when to drive and when better not to do so or adapt dynamically the vehicles driving behaviour and reroute based on this information (using motion planning).
- People tracking through phone app. The app acts as position sensor and this position data facilitates data-association and tracking for improving the AD vehicle’s World Model.

- Get actual weather and daylight information from internet. Reconfigure sensors to better perform under various weather and daylight conditions.

Extensions enabled by IoT

The integration of automated vehicles as IoT devices as well as IoT enabled VRUs enable their role as mobile sensors. That provides valuable information to the Mobility Management centre for traffic regulation and set a solid and valuable basis towards the management of hybrid traffic (automated/connected - non-automated/connected) in the AUTOPILOT cities which could be replicable to other cities.

Following an IoT architecture the information exchanged between all the mobility entities allow the automated vehicles access to:

- Pedestrian detection by infrastructure or other vehicles (I2V)
- Pedestrian detection by direct pedestrian to vehicle IoT communication (V2V)
- Pedestrian detection by vehicle (V2I)

IoT enabled functionality

- Pedestrian/obstacle awareness further than vehicle sensor range

The availability of such data on board has been tested and proved through C-ITS during the last years. Such info supported drivers of different vehicles and fleets. The interaction on that sense was limited to the information that a human driver can process, which is limited, in the case of hazards and traffic lights to the short term in a small radius (one or two intersections and close events).

The IoT approach opens the door to the access to a higher quantity of data that, in this case, can be processed by autonomous driving intelligence (for instance, the status of several intersections can be known and processed by the vehicle in combination with traffic status to take decisions on the best optimal route).

3.4.2.3.1 Hypotheses on IoT Impact

Benefits compared to state of the art are:

- Safer reactions in the presence of pedestrians and hazards
- Smoother driving behaviour
- The integration in IoT platforms of several communication channels 3G/4G, ITS-G5, LTEv2x increases the reliability by offering redundant information, enabling the use of the optimal communication channel according to data transmitted or complementary features in case of unavailability of any of communication channel

3.4.2.4 Performance Measures

Expected results with IoT in terms of the performance measures are:

- Lower max speed
- Higher min speed
- Average speed increasing
- Reduction in number of stops
- Reduction in number of hard braking
- Reduction in fuel Consumption & CO2 emissions

For Urban Autopilot with IoT Cooperative sensing:

- Pedestrian presence is detected at higher distance of intersection by IoT automated vehicle
- Pedestrian is detected earlier by the IoT automated vehicle

- Reduction of pedestrian detection time in vehicles
- Softer speed profile
- Softer acceleration profile
- Reduction of hard braking

3.4.3 Use case 4: Highway Pilot

Table 7: Mapping of use-case to AD modes, services, and applications listed in Chapter 2.

Automated driving modes	Services	Applications
Highway Pilot (Sec. 2.1.2)		6th sense driving (Sec. 2.3.2)

The Highway pilot use case addresses two classes of road hazards: fallen objects and road defects which are less critical hazards (not immediately life threatening). These hazards are major causes of damages and discomforts, and the end users complain about their vehicles not anticipating: neither alerting nor operating evasive manoeuvres when driving autonomous driving like a regular driver would.

Figure 45: Road features and hazards for Highway Pilot in Brainport.

Since it is not safe (risks of operating with hazards at higher speeds) nor practical (need to close partially the road for operation) to set up use case at N270 road from Helmond to Eindhoven, a closed road track has been set up at the Helmond Automotive Campus. The track nevertheless features regular lane markings, traffic signs as well as road hazards as depicted in Figure 45. The fallen objects class is represented by carton boxes or trash bags. The road defects class is represented by (speed) bumps and a pothole. The road presents many more surface defects (puddles and uneven surface), but for piloting only some major hazards lead to a driving adaptation.

3.4.3.1 Storyboard

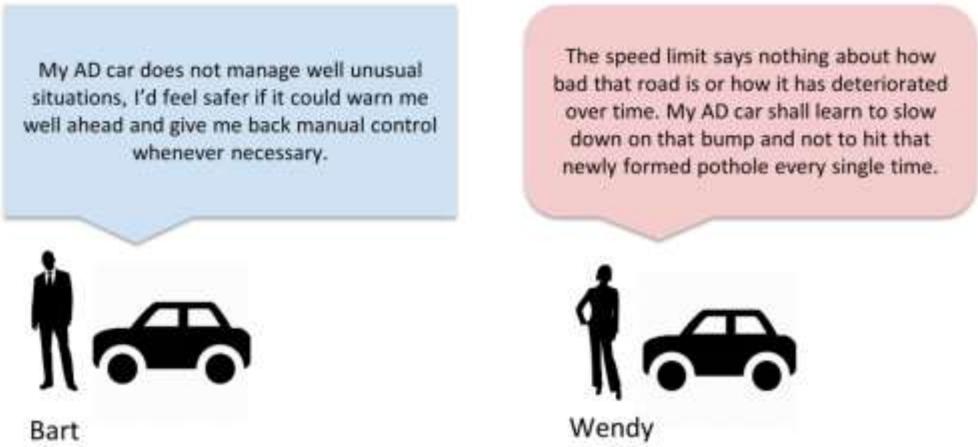


Figure 46: Storyline of road hazard warning

Motivation to include road hazard warning is depicted in Figure 46. In the storyline, a first car (Bart's) drives autonomously along the road but fails to notice ahead of time the road hazards. As the consequence, the car drives over them, resulting in some discomfort and maybe some damage. The car nonetheless reports the encountered anomaly to some online service. As this happens, roadside cameras also spot fallen objects on the road. This is illustrated in Figure 47.

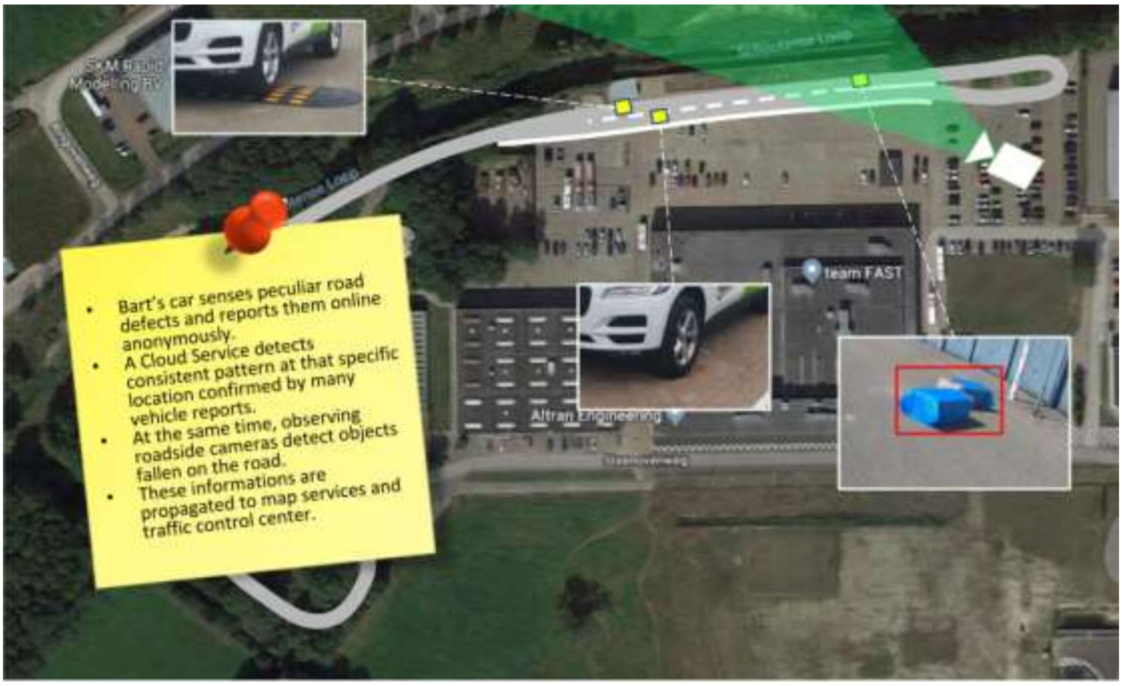


Figure 47: Road Hazards detection for Highway Pilot in Brainport

Moments later, Wendy's car enters that same road while driving autonomously. As it approaches the hazards locations, the car silently notifies Wendy with relevant alerts, and executes evasive manoeuvres with anticipation as if they were done by a driver familiar with the road. Wendy experiences a comfortable and safe journey in spite of the bad road conditions. This is illustrated in Figure 47 and Figure 48.

Figure 48 - Warning and Driving Adaptation for Highway Pilot in Brainport

3.4.3.2 Description (specifying AD driving mode, services and applications)

To enable the use case, we need the support of four technical functions: detection, learning, warning, and preventive manoeuvring. Following is a description of the use case from the points of view of vehicle, driver and traffic manager.

6th Sense Driving

6th Sense Driving anticipates on-road hazards by applying preventive AD manoeuvres. These AD manoeuvres are configured according to parameters presented in the table below:

Parameter	Description
Speed recommended	Sets a new speed target to the vehicle. Safety checks prevent this new speed from being excessively low (dangerous) or high (not above speed limit).
Time Interval	Sets a time interval to respect when following a vehicle. Due to piloting constraints (track and vehicles), this parameter is not used.
Avoid lane recommended	Tells the vehicle to attempt to change lane if on the same lane as the Road Hazards. If so, the vehicle triggers turning light. Note: during pilot, the actual steering is manually operated by the driver for safety.
Take over recommended	Tells the vehicle to give back manual control to the driver. On the piloting vehicle, this manifests by alarm noise and indicator.
Distance before	Tells how far before the Road Hazard location, the vehicle must start operating the preventive manoeuvre.
Distance after	Tells how far after the Road Hazard location, the vehicle must consider the preventive manoeuvre over and resume normal operations.

Table 8: AD driving mode configuration for Highway Pilot in Brainport

In-vehicle HMI: Hazards warnings and Driving Instructions

The vehicle does not just transparently apply the AD preventive manoeuvres. A complete HMI redesign of the Cluster Display (behind the steering wheel) provides information as shown in Figure 49 and Figure 50. The HMI has two distinctive features:

- It integrates in the centre a live map that highlights areas of concern (heatmap), exact location of hazard (warning sign), and presence of a driving instruction (blue info sign).
- It presents on the right-hand side, the type of preventive manoeuvre the vehicle is about to apply.

Figure 49 - Cluster Display of preventive manoeuvre (lane change) for Highway Pilot in Brainport

Figure 50 - Cluster Display of preventive manoeuvre (slow down) for Highway Pilot in Brainport

Traffic Management: monitoring application

The adaptation to AD driving mode is initiated by a traffic management person, who has the capability to analyse the hazards, who has sole authority and knowledge of the road, and hence the ability to propose the right instructions to drivers and autonomous vehicles. To help in this task, a monitoring application, illustrated in Figure 51, is provided. Its main features are map visualization, hazards information review, and driving instructions publishing.

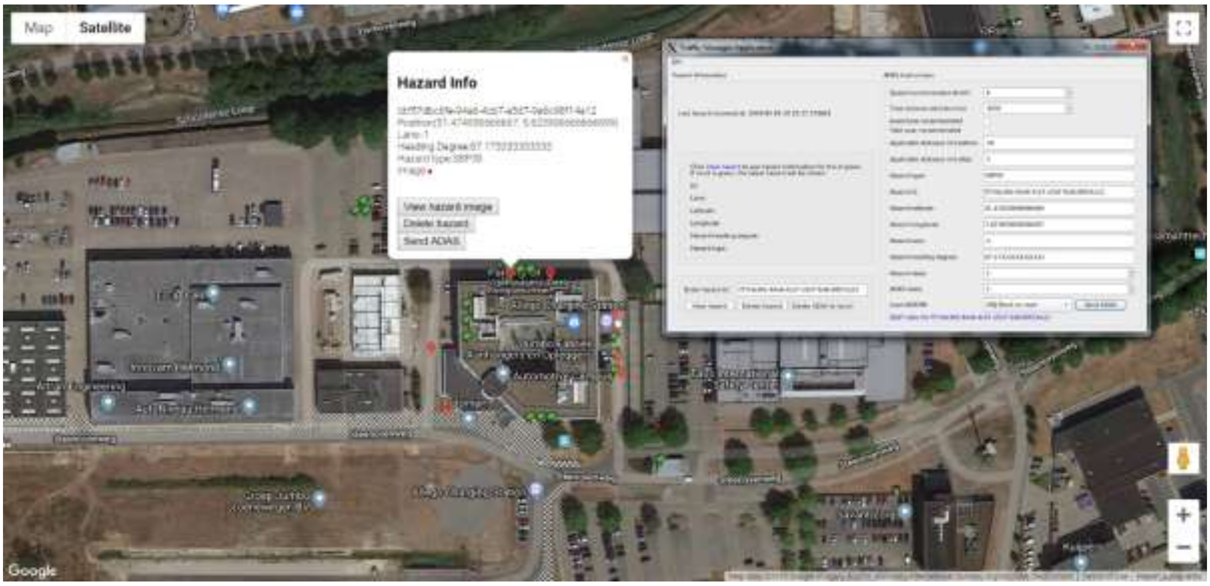


Figure 51 - Traffic Manager Monitoring Application for Highway Pilot in Brainport

3.4.3.3 IoT Utilization

To achieve the functional objectives, IoT is taken advantage of at two levels:

- at car level, with an internal IoT solution that simplifies the integration of different modules
- and more importantly, at system solution level, with a common standard IoT platform

IoT is indeed central in the information exchanges between the different subsystems of involved partners as illustrated in Figure 52 (IoT exchanges delimited by the yellow cloud).

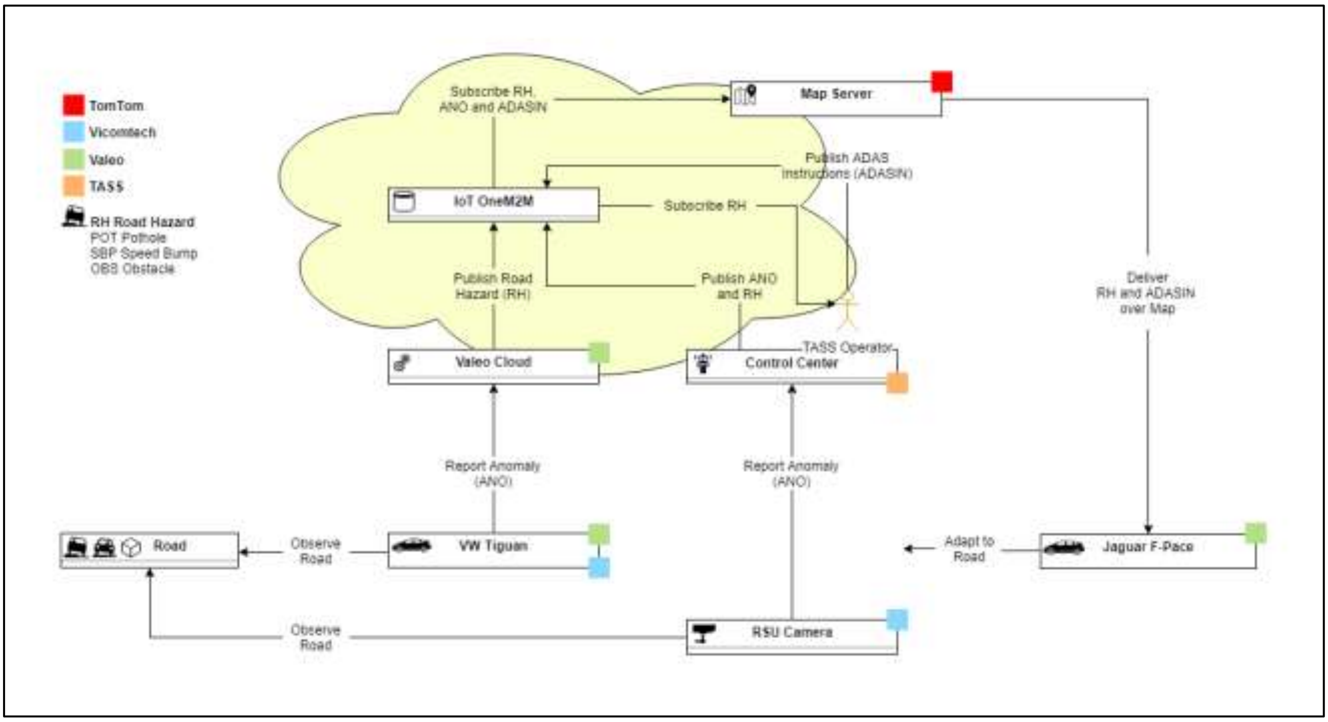


Figure 52: IoT usage in Highway Pilot at Brainport

3.4.3.4 Hypotheses on IoT impact

The direct impact of IoT is the great facilitation of the integration of the solution subsystems:

- easier inclusion of additional road hazards detection sources (more sensors in vehicles, more vehicles on the road, and cameras on road side)

- more streamlined and frequent detection reports
- easier integration of a solution subsystem
- transparent and timely propagation of information across subsystems

For the use case, these technical consequences translate into:

- smaller road defects being also detected
- warnings communicated to vehicles/drivers/passengers being more relevant and descriptive of Road Hazards ahead
- AD applying more progressive and smoother manoeuvres when passing over or around Road Hazards
- drivers and passengers having the perception of a more comfortable and safer journey
- vehicles being preserving from cumulative damage

3.4.3.5 Suggested Performance indicators

Some indicators of performance are:

- accuracy of the location of hazards thanks to the many detections and in spite of standard GPS accuracy
- delay in road hazards detection from first anomaly report to confirmed hazard
- manual driving quality perception by passengers, with and without warning + instructions
- AD driving quality perception by passengers, with and without warning + instructions
- speed of information propagation between different systems of the solution
- proper and timely reception of warnings in vehicles
- proper and timely application of driving instructions sent to vehicles

3.4.4 Use case 3: Automated Valet Parking (AVP)

In the AUTOPILOT-project, the AVP-demonstration took place at the Helmond Automotive Campus. An overview of the site is presented in Figure 53. In this figure, the roads are green, the parking spaces are indicated with a blue colour, and the drop-off and collect point are represented by the red coloured rectangle, located just in front of the main entrance of the yellow TNO-building.

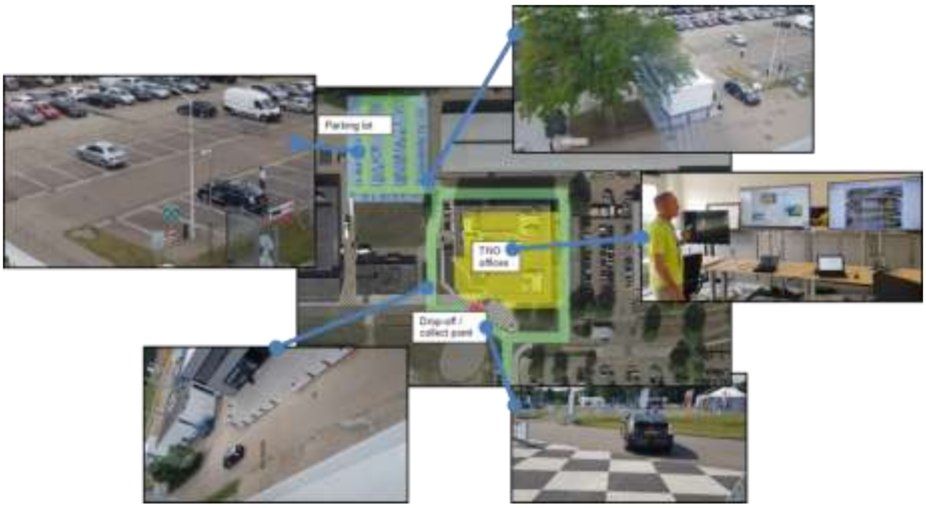


Figure 53: Layout of the AVP demonstration site (source: google-maps).

3.4.4.1 Storyboard

The use case story starts with the vehicle being manually driven to the drop-off point in front of the TNO building. After arriving there, the user activates the AVP function (e.g. by in-vehicle interface or smartphone app) and exits the vehicle. Services on the IoT platform determine an obstacle-free route to a parking position based on information of the IoT infrastructure (such as cameras, drones and other IoT-enabled vehicles). The vehicle autonomously drives to the dedicated parking position.

Step 1: Arriving at the drop-off position

Step 2: AUTOPILOT-AVP App requesting a parking spot

Step 3: Fixed cameras updating parking spot occupancy status

Step 4: Drone searches and confirms a free parking spot

Step 5: App displays the route to the parking lot

Step 6: Automated parking at the parking spot

Figure 54: AVP use case storyboard

Later, the user can use the smartphone app to call the vehicle to the pick-up point. The detailed description of AVP is depicted in Figure 54.

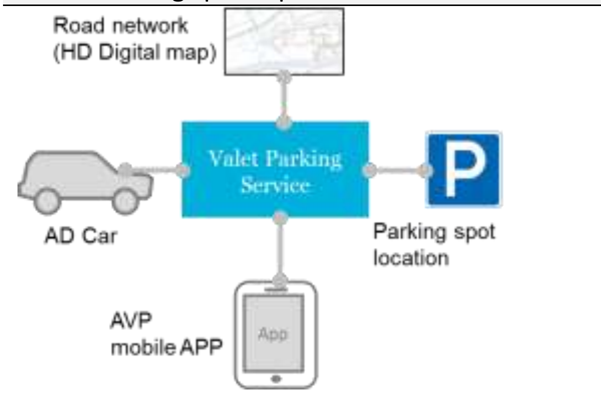
3.4.4.2 Description (specifying AD driving mode, services and applications)

The aim of the AVP AD driving mode is to optimise the parking procedure by using IoT. In this context optimisation means to reduce the time of searching for an empty parking lot, thus selecting the most efficient trajectory from a drop-off/pick-up to parking-space position. As service the car driverless moves from a drop-off/pick-up to a parking-space position and automated optimises its driving route by knowing via IoT if there are any obstacles on different route alternatives. The core of this driverless car service and automated driving route optimisation application is the Park-Management-Service (PMS). The PMS guarantees that after a parking request of a driver all the information available of the parking area are retrieved. This information can be for example, the availability of an empty parking lot, the position of an empty parking lot closest to the drop-off/pick-up point, the shortest route from drop-off/pick-up point to empty parking lot, the fastest route from drop-off/pick-up point to empty parking lot, obstacles on the route, which stops driving, and so on. Based on this information, which is retrieved from IoT devices like cameras, drones, etc. the PMS calculates the most efficient route for the vehicle and sends the parking request to the car, which starts driving and parking. The same procedure is valid when the driver calls the vehicle via his/her smartphone app from the parking lot to a pick-up point.

3.4.4.3 IoT Utilization

With the ongoing trend towards self-driving cars, near-future production vehicles will in general be capable of performing the AVP task. The main challenge is, however, the environment perception to be performed by the vehicle, and a suitable common architecture of sharing information between different brands and sensor systems, such that any vehicle can park itself in *any* parking garage. For those cases in which the parking lot is equipped with an extended set of sensors, more and accurate information can be shared to the AVP-vehicle, such that it can better (more accurate, more efficient) perform its task, compared to parking lots that lack those sensors.

Automated Valet Parking (AVP) implementation	
Option 1: Without IoT Parking spot exploration is needed	Option 2: With IoT No need of parking spot exploration



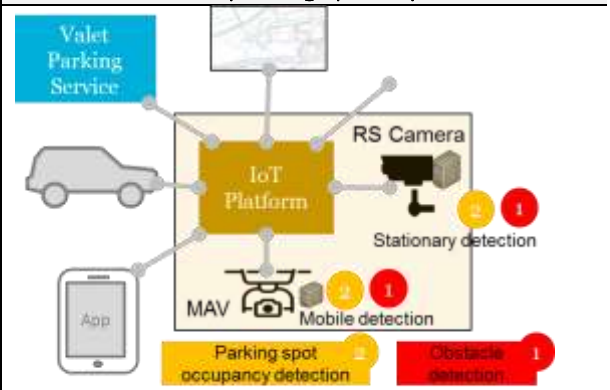


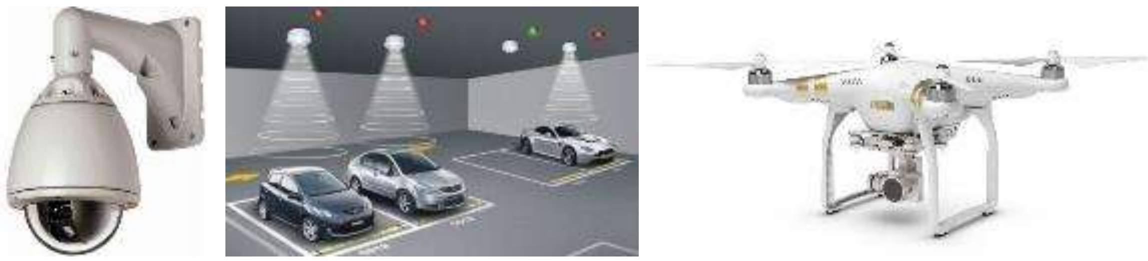
Figure 55: Automated Valet Parking (AVP) implementation

The concept of IoT is used here to connect to and combine several sources of information, such that the AVP-vehicle can perform its parking task in the most efficient way as indicated in Figure 55. The influence of IoT on the AVP efficiency will be investigated in detail.

Below, an overview of different information sources is presented which may be used in AUTOPILOT, see also Figure 56:

- Cameras at fixed positions in and around parking area (see Figure 56)
- Parking spot detection sensors (see Figure 56)
- Using camera/radar information from other (driving and/or parked) vehicles
- Car-following drones that can aid less-equipped vehicles, or can be used at less equipped parking lots (see Figure 56)
- Inductive-loop traffic detectors (such as commonly used for traffic lights)
- Usage of statistic models in traffic management systems to avoid congestions

As mentioned in the state-of-the-art, with respect to AVP, TNO has traditionally focussed on path tracking control. Localization and environmental perception, which are key to a properly working AVP-function, were left unaddressed and need significant development.



(a) (b) (d)

Figure 56: Some examples of different information sources which can be used for AVP.

In the AUTOPILOT project, TNO focuses on mapping and localization using both on-board sensors as well as the previously listed external sources of information.

IoT is expected to significantly enhance the AVP use case. The two main extensions enabled by IoT are an improved modelling of the vehicle's environment, i.e. the parking lot and its static and dynamic parameters and the ability to externalize functionality.

One of the major challenges in the use case is to construct a comprehensive model of the environment. Vehicles present on the parking lot, parked or driving, are obstructing the sensors of an automated car. Other information like obstacles blocking routes or where the last few free spots might be, may be well completely out of sensor range. This considerably hinders efficient planning of parking route and manoeuvres and might restrict the automated car to an overly cautious driving behaviour. Connecting the vehicle to IoT will considerably mitigate these issues. Exploiting existing infrastructure, sensors outside of the automated vehicle makes IoT-capable and connected to the vehicle via an IoT-platform. These are in Brainport surveillance cameras as well as off-the-shelf sensors equipped on series vehicles such as ultrasonic sensors. Furthermore, by the introduction of drones as a kind of sensor extension, information about areas previously uncovered is provided. The vehicle can incorporate the additional information in its environment model and its driving functions. The various types of IoT sensors provide information about parking space, other road users and additional reference points for improved positioning accuracy. The use of these sensors' information will make the use case more efficient and enhance safety by redundancy.

The approaches described in the state of the art primarily suggest the functions for AVP to be running entirely on the automated vehicle. Connecting the vehicle to IoT-platforms not only allows shared access to sensors but also to shift functionality from the vehicle to the IoT-platform. By allocating functionality to the IoT-platform like the PMS, the platform can coordinate traffic on the parking lot and do efficient route planning based on real time available traffic flow information. This helps with avoiding blocked routes and congestions and results in time saving for the driving in delivery and return processes. Also, user-specific data can be used to make the use case more efficient, for example by anticipating the vehicle return time using the driver's calendar. Besides navigation, also functionality on the tactical decision level may be shifted to the IoT-platform so that less functionality is required on the vehicle itself. Combined with the additional sensors provided by IoT, function externalisation opens the use case for vehicles that would otherwise not be capable of doing automated valet parking. The purpose of function externalization is not to unburden the automated vehicle, but rather to hand off decisions to an entity which has better knowledge of the overall situation and can thusly plan more efficient routes to follow.

3.4.4.3.1 Hypotheses on IoT Impact

The hypotheses concerning the impact of IoT on Automated Driving retrieved from an expert assessment are listed below:

- IoT makes the AVP use case more efficient, expressed in reduced travel times for drop-off and pickup.
- IoT increases safety by allowing access to additional sensor information.
- IoT can lower the entry barrier for the adoption of AVP by providing an efficient framework which can greatly improve the parking process.
- IoT can benefit non-AD vehicles as well.
- Reduced travel times to drive to / from parking spot
- Reduced distance to drive to / from parking spot
- Improved detection of other road users (pedestrians, vehicles)
- Reduced number of deadlock situations
- Decomposition / Relocation of AD functions to edge / cloud backend systems

3.4.4.4 Suggested Performance indicators

In this chapter performance indicators are suggested to measure the impact of IoT on Automated Driving. The performance indicators were retrieved from an expert assessment:

- Position accuracy
- Time to park
- Waiting time / time to return vehicle
- Number of conflicts (e.g. due to an unforeseen obstacle)
- Latency of detection
- Energy consumption
- Variation in speed profile
- Variation in number of hard braking/accelerations
- Number of drive direction changes

3.4.5 Mobility Service

In Brainport, an umbrella Mobility Service has been developed and demonstrated (not piloted) which targets a more complete end user experience. This service is in essence a light integration of the platooning and AVP use cases with the ride sharing service acting as the actual umbrella service.

Automated driving modes	Services	Applications
Platooning AVP	Mobility Service Car/Ride sharing service	AD route optimisation

3.4.5.1 Storyboard

For the storyboard, we refer to the storyboard described for the Platooning use case in Brainport with Bart and Wendy. The main character in the Mobility Service is Wendy, requesting for a car and the ride share via a smart phone app (equipped with eDriving License). Her car/ride share request can be matched with the ride of Bart who like Wendy also drives from Helmond to Eindhoven. The car that was requested by Wendy is driven automatically from the parking lot on the Automotive Campus to the front entrance of the campus after which she enters the car and prepares for engagement in the platoon formation.

3.4.5.2 Description (specifying AD driving mode, services and applications)

AD driving modes used are Platooning (see Section 3.4.1.) and AVP (see Section 3.4.4.). Only part of the full AVP functionality is used in this use case, i.e. the capability to leave the parking lot and drive automatically to the pick-up point, at the entrance of the Automotive Campus main building entrance.

3.4.5.2.1 Mobility service

The mobility service is the umbrella service and has the following functionalities:

- It facilitates the mobility needs from destination A to B possibly using different other services
- Interacts with car/ride sharing service, platooning service and valet parking service
- Operates on strategic driving task level

The smart phone app developed to request the Mobility Service is shown in Figure 57.

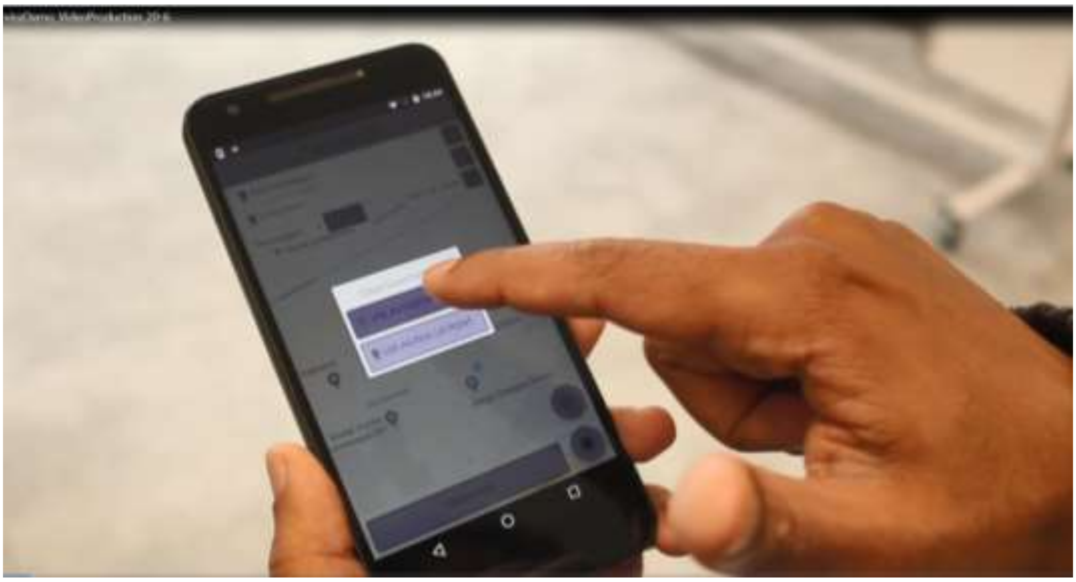


Figure 57: Smart phone app to request the Mobility Service

3.4.5.2.2 Car/Ride sharing service

The Car/ride sharing service which is originally developed for large fleets, is adjusted to the AUTOPILOT project and the Brainport situation. The service has the following functionalities:

- The car/ride sharing service matches vehicles with customers' requests of origin and destination locations and several other requests (ride alone or with somebody, possibly time-windows).
- It interacts with the AVP parking management service to request for a car for Wendy, and with the platooning service to notify this service of two vehicles of which the users (drivers) are matched.
- It provides an initial route advice to the platoon service.
- It monitors the actual 'whereabouts' of the vehicles of the mobility service clients (Bart and Wendy).
- It operates on strategic driving task level.

3.4.5.2.3 Authentication service

The Authentication service developed has the following functionalities:

- Authenticates users requesting IoT services such as car/ride sharing, valet parking
- Authenticates users to enter the car
- Provides non-repudiation the user entered the car
- Privacy friendly authentication with anonymous or semi-anonymous authentication

3.5 Spain - Vigo

The pilot site of Vigo, Figure 58, is in the north west of Spain. It is integrated in the urban section of SISCOGA corridor. It is extended along more than 100 Km of urban and interurban roads in A55, A52, VG20 and AP9 highways. The access to Vigo from AP9, A55 and VG20 are linked across the city roads through the main city streets.

SISCOGA facilities has enabled testing and development of multiple ITS solutions from C-ITS systems, ADAS, eCall and Electro mobility, especially those involving V2X communications. Some examples of local and European projects, which have been tested in SISCOGA facilities, are: DriveC2X, Compass4D, CO-GISTICS, CO2PerautoS2, OpEneR, Mobinet, HeERO2, etc.

Figure 58: Vigo Pilot Site testing scenarios.

Both, urban and interurban sections are connected to management infrastructures from the competent road authorities, Vigo Mobility and Safety Area and DGT respectively.

Vigo Pilot tested mainly 2 use cases with several configurations and combinations.

1. Urban Driving was tested in CTAG test tracks, where scenarios were reproduced and later in real conditions in the Gran Vía Avenue through a fixed route which included one traffic light intersection. Pedestrian detection by infrastructure was tested as well.
2. Automated Valet Parking was tested in the City Council Parking. The main challenge of such a parking lot is the indoors positioning, which was solved by access to cameras and parking spaces sensors through IoT connectivity. The testing area was selected among their 200 parking spaces and took place in the 1st of its two levels. Before starting parking testing some pre-tests were carried out in reproduced scenarios at CTAG test facilities.

3.5.1 Use Case 1: Urban Driving

The aim of this use case is to support automated driving by providing information that is out of the range of the sensors of the automated driving vehicles through an IoT platform. Information provided included mainly traffic light status and time to change of signal at the intersection together with information about pedestrians (or other warnings) on the road. Such information may be out of the sensors' range either because they are too far or because an obstacle (e.g. another vehicle) is present.

In this sense, the main capabilities of Urban Driving assisted by IoT will be:

- Adaptation of speed circulating in urban roads in autonomous mode according the status and remaining time to change of traffic lights.

- Reacting in advance to potential warnings received by IoT Cooperative Sensing about hazards provided by TMC or other vehicles (pedestrian, accident, road works, etc.)

3.5.1.1 Storyboard

The way this use case works could be explained by the storyboard shown in Figure 59. The story starts when the driver of a car sends a request to initiate the AD mode. The traffic management centre confirms use of AD mode in that lane. The car gets access to information relevant for the current autonomous driving path. The driver starts the relevant functions. The car adapts its speed to provide a smoother intersection crossing and reacts to pedestrian presence when notified by the IoT platform.

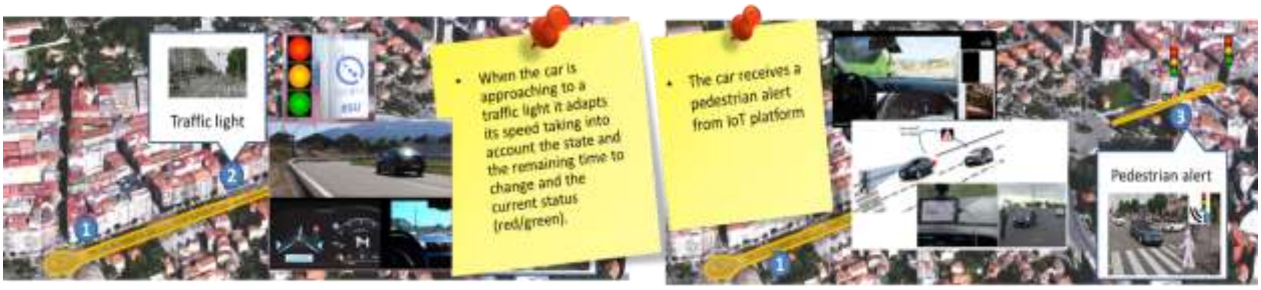


Figure 59: Vigo Pilot Site urban driving overview. Speed Adaptation according to traffic light status and time to change and pedestrian awareness from infrastructure/vehicle detection.

3.5.1.2 Description specifying AD driving mode, services and applications

Scenario: Traffic light (TL) speed adaptation

Active entities and information exchange of this scenario are listed below:

- The Traffic Light Control Unit acts as an IoT device integrated in IoT ecosystem and connected to IoT platform.
- Vehicle IoT platform connects to City IoT platform and request relevant information according its position and heading (and/or route).
- IoT platform sends data relevant according the position, heading and (and/or route) using the most suitable communication channel. In this case traffic light status and time to change for the next intersection(s) according heading (route).
- Cars have access to information about the remaining time to red or green light.
- They adapt their speed to provide a smoother intersection crossing and reduce consumption and pollution.

Scenario: Pedestrian Alert (Cooperative sensing)

Active entities and information exchange of this scenario are listed below:

- Traffic light cameras are part of IoT ecosystem and detect pedestrian. This information is available in the City IoT platform.
- Vehicles, as IoT device and part of IoT ecosystem, share the pedestrian detected in the road.
- Other vehicles, as IoT entities in IoT ecosystem, has access to this information when according their position and heading is relevant for the automated driving task.

- Automated vehicle reacts accordingly when relevant pedestrian presence is notified from IoT platform.

3.5.1.3 IoT Utilisation

The integration of automated vehicles as IoT devices in the Smart City platform enables their role as mobile sensors. This provides valuable information to the Mobility Management centre for traffic regulation and sets a solid and valuable basis towards the management of hybrid traffic (automated/connected - non-automated/connected) in the city of Vigo, which could be replicable to other cities.

On the vehicle side, the electronic horizon extension is taken to a new dimension. With C-ITS communication range is limited to the traffic lights of the approaching intersection. IoT integration sets the basis for enabling access to a wider volume of data (different traffic lights, routing, pedestrian, hazard warnings, priority to automated vehicles).

IoT utilization in the Vigo pilot site for urban automated driving in city roads with access to the different traffic lights across the route using IoT platforms (on board and infrastructure) together with V2X warnings is shown in Figure 60.

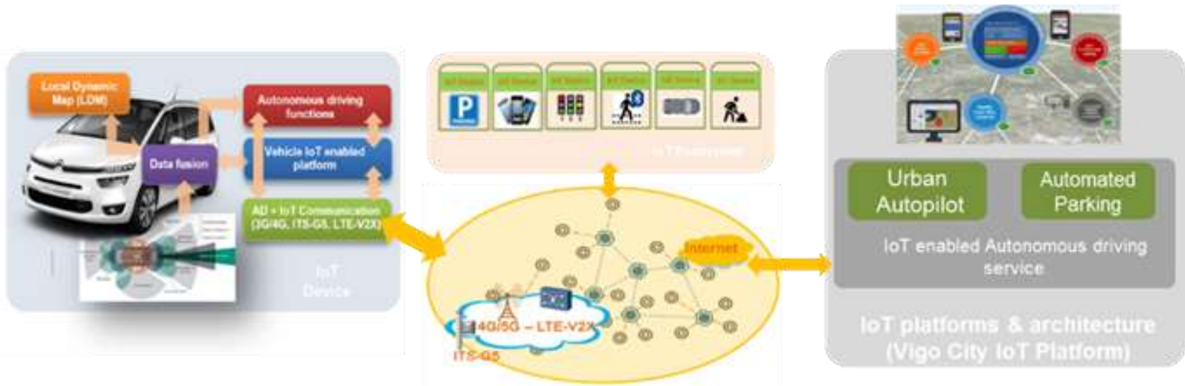


Figure 60: IoT utilization in Vigo pilot site.

The vehicle has access to traffic light status/timing and hazard warnings through real time connection to infrastructure IoT platform. Each vehicle acts as mobile sensor and interchanges information with infrastructure and other vehicles. Infrastructure sensors and cameras are integrated in such data interchange. Information provided by IoT includes:

- Traffic light status and time to change (infrastructure to vehicle).
- Hazard warnings (infrastructure to vehicle).
- Pedestrian detection by infrastructure (infrastructure to vehicle).
- Pedestrian detection by vehicle (V2V and V2I).

3.5.1.3.1 Hypotheses on IoT impact

- Speed adaptation to traffic light remaining time.
- Pedestrian/obstacle awareness further than vehicle sensor range.
- Speed adaptation to hazards - road works, traffic jam or accident.

Benefits compared to state of the art

- A more reliable perception of traffic light status.
- Wider range of information of route traffic lights and potential adaptation of route speed.

- Anticipation improvement with extended perception further of own vehicle sensor range.
- Safer reactions in the presence of pedestrians and hazards.
- Smoother driving behaviour.
- The integration in IoT platforms of several communication channels 3G/4G, ITS-G5, LTE-V2X increases the reliability by offering redundant information, enabling the use of the optimal communication channel according to data transmitted or complementary features in case of unavailability of any of communication channel.

3.5.1.4 Suggested Performance Indicators

- Number of hard acceleration events.
- Number of hard braking events.
- Time of detection of pedestrian by the vehicle.

3.5.2 Use Case 2: Automated Valet Parking

3.5.2.1 Storyboard

The automated valet parking storyboard is shown in Figure 61. The driver is able to book a parking space in a parking lot through mobile app. The driver leaves the vehicle at the drop-off area and the vehicle drives to the parking space and parks on automated mode supported by data available by IoT platforms (map, parking space position, parking sensor/cameras, vehicle position, etc.).

Figure 61: Automated valet parking storyboard

The driver requests the vehicle through a mobile app and the sequence of leaving the parking space and driving to pick up area is performed in automated mode supported in the same way by the data accessible through IoT platform. The driver pays via the app and takes the vehicle.

The vehicle establishes connection with the parking infrastructure (through IoT platforms) to have access to information from parking cameras and sensors together with parking mapping and instructions (such as free lane: you can leave parking space) according to internal traffic. In this way, manoeuvres are supported by information from parking cameras and sensors together with parking mapping and instructions according to internal traffic.

3.5.2.2 Description specifying AD driving mode, services and applications

Active entities and information exchange of drop-off are listed below:

- The driver leaves the vehicle at the drop-off area after booking and gets a confirmation of parking space.
- The parking management system identifies and admits the automated vehicle.

- Information exchange takes place between vehicle and Parking management system which includes parking map, parking spot and additional info from cameras and/or sensors in the parking lot.
- The Vehicle drives in automated mode towards the assigned parking space supported by external info from the parking management system (access to connected elements, indications and/or orders according to Parking lot situation in terms of traffic).
- Once in the parking space, the vehicle performs the parking manoeuvre and switches off when finished.

Active entities and information exchange of drop-off are listed below:

- The driver activates the return order to parking management systems.
- The Parking Management Systems authorize the AD vehicle exit and provide instructions which includes parking map, parking exit route and additional info from cameras and/or sensors in the parking lot.
- The vehicle gets out of the parking space and drives in automated mode towards the pickup area with the support of the Parking Management System.
- The driver gets into the vehicle and continue his/her journey.

3.5.2.3 IoT Utilisation

IoT utilization in the Vigo pilot site is shown in Figure 60. In this use case IoT is used for assigning a parking spot, communication of virtual parking map as well as positioning and routing support without GMSS signal. Information provided by IoT includes:

- Parking map
- Parking space position
- Optimal route according to parking situation
- Parking sensors/cameras information
- Vehicle speed
- Vehicle sensors info

Vehicle performs automated driving based on the parking map provided and additional info from sensors and cameras.

3.5.2.3.1 Hypotheses on IoT impact

- Parking management improvement:
    - Time saving for the driver:
        - Vehicle delivery: saving time for accessing, looking for parking space, parking, walking to parking lot exit
        - Vehicle return: Walking to casher, paying, walking to vehicle, leave parking space, drive to parking exit
- Safer improvement with parking support provided

3.5.2.3.2 Benefits compared to state of the art

- Possibility of parking underground (no GNSS signal available)
- Time saving for the driving in delivery and return processes
- Possibility of managing several automated vehicles parking traffic
- No need of parking drivers

3.5.2.4 Suggested Performance Indicators

- Time to park
- Waiting time / time to return vehicle
- Latency of detection

3.6 Korea - Daejeon

The Korean site includes a test site at K-city in Hwaseong, southwest of Seoul and pilot site at ETRI in DAEJEON, which is 150km south of Seoul. ETRI pilot site focuses on the deployment of an Intersection Safety Information (ISI) system in an Urban Driving use case. ETRI pilot site is a convenient and efficient location to test it, since ETRI has developed V2X communication and ISI service concept and the research staff mainly work at ETRI campus. The pilot site includes a test road of 150m, a two-lane road and one intersection. Infrastructure facilities are installed for an IoT-based ISI system. The test site K-city has been built for automated driving tests and provides intersection test facilities including V2X communication network, traffic light and integrated traffic centre. Thus, ISI testing has been performed at K-city as shown in Figure 62 and Figure 63, and piloting was carried out in real traffic environments at ETRI pilot site as shown in Figure 64, Figure 65 and Figure 66.

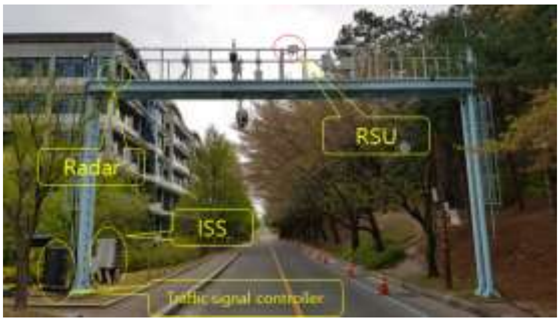


Figure 62: Road infrastructure with road radar and RSU and traffic signal controller at ETRI site.

Figure 63: Vehicle mounted service terminal in ETRI site.

3.6.1 Use Case: Urban driving

3.6.1.1 Storyboard

Crossing an intersection is challenging for automated vehicles due to many obstacles like pedestrians and other vehicles crossing the road and traffic signal phases. The urban driving use case addresses the provision of an Intersection Safety Information service that warns vehicles about pedestrians in order to avoid accidents. The road is equipped with a radar that detects pedestrians and transmits information to the vehicle's OBU. The OBU receives information from the road radar and traffic signals and includes this information in its LDM as well as displays it in the user interface.

Figure 64: Test road for automated urban driving in K-city.

Figure 65: Road infrastructure with road radar and RSU and traffic signal controller in K-city.

Figure 66: Vehicle mounted service terminal in K-city.

Two scenarios considered in this use case are intersection violation warning and pedestrian warning as shown in Figure 67 and Figure 68.

Service flow: Intersection violation warning

1. The driver stops at the intersection and tries to turn left while waiting for the traffic signal to change to green-go state. The road radar scans the road status in real time. If vehicles are detected, the detected information is sent to ISS.
2. The traffic signal is connected to ISS and the traffic signal phase information is sent to ISS periodically.
3. ISS receives the detected vehicle information from the road radar and the traffic signal phase information. ISS combines the two sets of received information and sends it to service terminal. The service terminal decides whether the moving vehicle is in the intersection zone and would cause a collision with the ego vehicle turning left. Finally, the service terminal generates a warning signal.

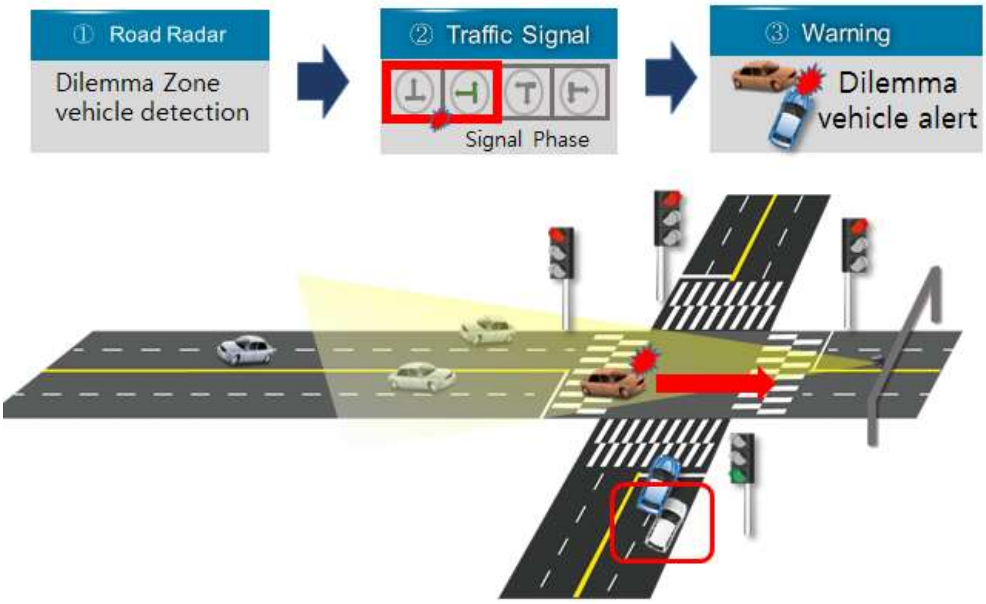


Figure 67: Intersection violation warning in urban driving.

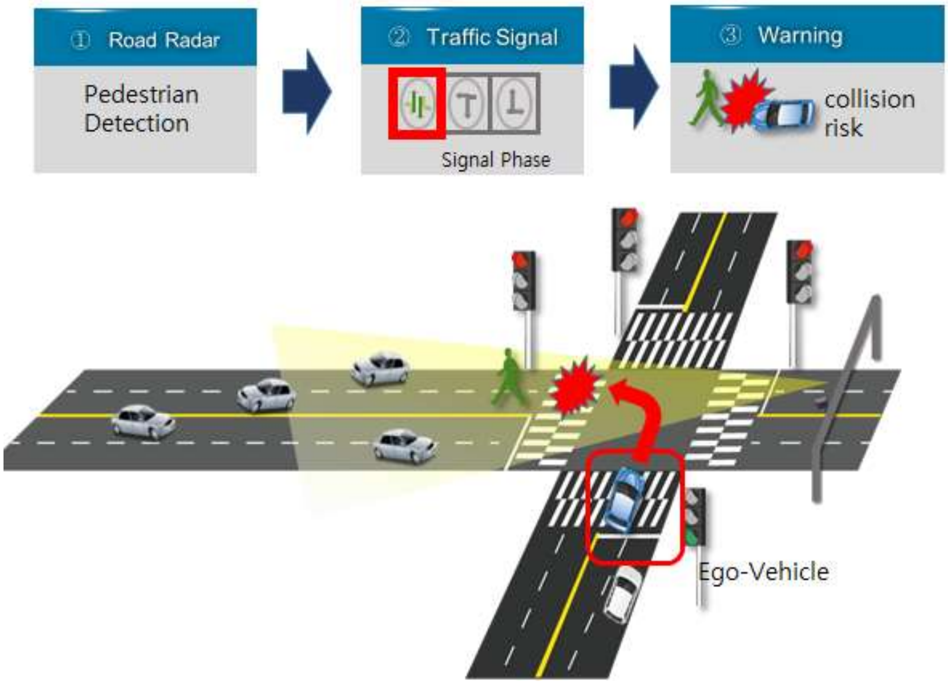


Figure 68: Pedestrian warning in urban driving.

Service flow: Pedestrian warning

1. The driver stops at the intersection and tries to turn left while waiting for the traffic signal to change to green-go state. The road radar scans the road status in real time. If pedestrians are detected, the detected information is sent to ISS.
2. The traffic signal is connected to ISS and the traffic signal phase information is sent to ISS periodically.
3. ISS receives the detected pedestrian information from the road radar and the traffic signal phase information. ISS combines the two sets of received information and sends it to service terminal. The service terminal decides whether the pedestrians are in crosswalk zone and would cause a collision with the ego vehicle turning left. Finally, the service terminal generates a warning signal.

3.6.1.2 Functional Description

The Korean pilot site consists of an infrastructure system and a service terminal. The intersection safety system architecture is shown in Figure 69. The ISI infrastructure system installed at the intersection area generates the intersection safety information in real time. The infra sensors (road radar and camera), traffic signal and GPS are connected to the ISS system. The ISS system combines the received information from infra sensors, traffic signal and GPS and generates intersection safety information, which is sent to the IoT server and RSU.

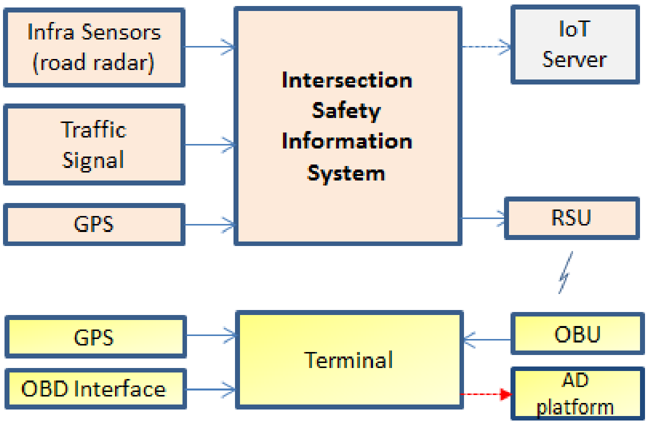


Figure 69: Intersection safety system architecture

The OBU receives the intersection safety information and knows the vehicle's location from GPS and accurate location by compensating location error and also the vehicle's driving status such as vehicle speed. By estimating the vehicle location, the OBU decides whether the moving vehicles are in intersection zone or not. Additionally, the OBU decides whether the pedestrians are in the crosswalk zone or not when the traffic signal turns to green. Finally, the service terminal generates a warning signal, or it may generate a command to the AD platform to slow down or stop.

3.6.1.3 IoT Utilization

IoT is used for collecting and utilizing data from the traffic signal and fixed radar (to detect pedestrians) and the camera installed at the intersection. ISI generates relevant IoT data, which contains LDM and road status information regarding pedestrian. This enhances the perception of the automated driving vehicle at the equipped intersections towards the goal to realise a fully automated driving at the equipped intersections.

The ISI system has been developed based on the MESIM IoT platform and its information is exchanged with the European AUTOPILOT platform.

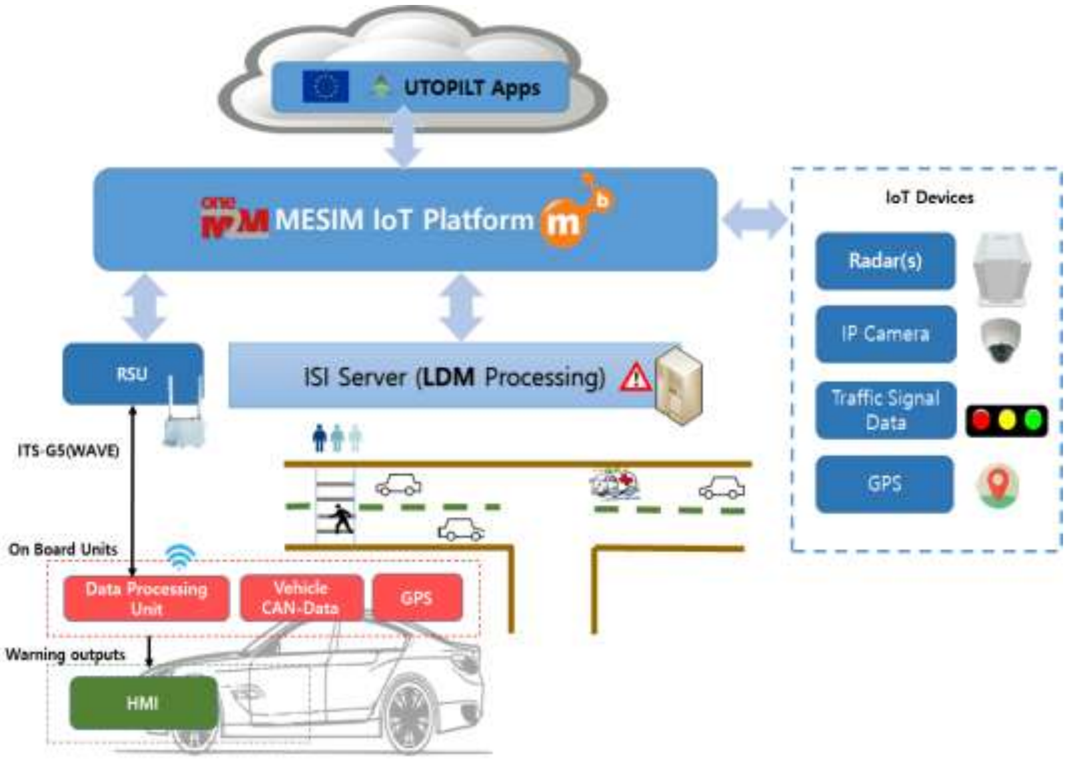


Figure 70: IoT platform architecture for urban driving in Korea pilot site.

The IoT platform is connected to each pilot platform and exchanges information by using a common data model. The common data model contains location and attributes including persons and things. Authentication and security protection are provided while it should meet message reliability. Figure IoT platform architecture is shown in Figure 70.

3.6.1.4 Hypotheses on IoT impact

- IoT helps the vehicle to detect vulnerable road users.
- IoT helps the vehicle to anticipate dangerous situations.

3.6.1.5 Suggested Performance Indicators

The intersection safety warning service will provide real-time and reliable information. The intersection safety information is sent to the OBU every 100 millisecond. And the safety information may have message errors because it is delivered to OBU via I2V radio communication and message error rate shall be less than 10% and command message error rate for automated driving shall be less than message error rate of the warning signal. Suggested performance indicators are:

- Reduction of the number of hard braking at intersections.
- Pedestrian presence is detected at greater distance by IoT automated vehicle.
- Reduction of speed of the AD vehicle when approaching a VRU or vehicle on collision course.

4 Conclusions and summary of use cases

The document presented the final specification of IoT-enabled Automated Driving use cases based on the experience gained during the realization of the project as well as from the piloting activities. The specification includes the functional description as well as the state-of-the-art of the use cases categorised according to the automated driving modes, and their related services and applications. Four automated driving modes, three services and four applications are specified in the document. Automated driving modes specified are automated valet parking, highway piloting, platooning, and urban driving; services specified are real-time ride sharing, driverless car rebalancing, and car sharing and city chauffeur services for tourists; and applications specified are automated driving route optimization, 6th sense driving and dynamic eHorizon.

The deliverable also provides the specification of the use cases based on how they are realized in the five European pilot sites and the Korean site. To realize the use cases, in addition to the automated driving modes, services and applications mentioned above, several other functional components were developed and implemented. They were applications or services to end users. Table 9summaries the use cases along with the AD modes, services, application and additional services/application realized in the six pilot sites.

Table 9: Overview of Automated Driving use cases in pilot sites.

Pilot site	Use case	Automated driving modes	Services	Applications	Additional services/applications
Finland Tampere	Urban Driving	Platooning	None	Driving Route optimisation	VRU detection Automated intersection crossing
	Automated Valet Parking	Automated Valet Parking	None	None	Parking management VRU detection
France Versailles	Urban driving with car sharing and city chauffeur services for tourists	Urban Driving	Car sharing and city chauffeur services for tourists	None	POI notification VRU detection
	Platooning for automated fleet rebalancing	Platooning Automated Valet Parking	Driverless car rebalancing	None	Automated intersection crossing Platooning service
Italy Livorno	Highway Piloting	Highway Piloting	None	Dynamic eHorizon	Traffic management
	Urban driving	Urban driving	None	None	VRU detection
Netherlands Brainport	Platooning	Platooning	None	Driving Route optimisation	Platooning service Local dynamic map
	Urban driving with driverless car rebalancing	Urban driving	Driverless car rebalancing	6th sense driving	Crowd Estimation and rerouting Collaborative Perception

	Highway Piloting	Highway Pilot	None	6th sense driving	Traffic management
	Automated Valet Parking	Automated Valet Parking	None	None	Parking management
	Mobility Service	Platooning Automated Valet Parking	Ride sharing	Digital driver license Automated driving route optimization	Platooning service Local dynamic map
Spain Vigo	Urban driving	Urban driving	None	None	VRU detection Automated intersection crossing
	Automated Valet Parking	Automated Valet Parking	None	None	Parking management
Korea Daejeon	Urban driving	Urban driving	None	None	VRU detection Automated intersection crossing

The main characteristics of the four AD driving modes collected from the use cases are listed in Table 10.

Table 10: Overview of Automated Driving modes for pilot sites.

AD modes	Finland Tampere	France Versailles	Italy Livorno	Netherlands Brainport	Spain Vigo	Korea Daejeon
Automated Valet Parking	Parking lot (20 cars)	Road-side dedicated parking	N/A	Parking lot (180 cars)	Parking garage (200 cars)	N/A
Highway Pilot	N/A	N/A	Integration with real Highway Traffic Control Centre	Regular road with diverse hazards (test track on Automotive Campus), 2 vehicles	N/A	N/A
Platooning	N/A	5 identical vehicles, 30 km/h	N/A	3 vehicle variants, 100 km/h	N/A	N/A
Urban Driving	Controlled intersections	Road network, controlled intersections	Controlled intersections	Road network, uncontrolled intersections	Controlled intersections	Controlled intersections

This deliverable also specified how Internet of Things is expected to progress Automated Driving beyond the state-of-the-art, especially on the four automated driving modes. The hypotheses on expected impact of the integration of Internet of Things in the use cases and the suggested performance indicators to support the evaluation activities are also specified in this deliverable. A summary of the hypotheses proposed and suggested performance indicators for the four AD modes are provided in Table 11.

Table 11: IoT involvement in use cases, services and expected impacts.

AD modes	Hypotheses on IoT impact	Suggested performance indicators
Urban Driving	• Smoother driving behaviour and higher in-vehicle comfort • Detection of vulnerable road users or dangerous situations • Better perception of traffic light status	• Reduction of the number of hard acceleration/braking • VRU detection at larger distance or reduction in detection time • Reduction of speed when approaching a VRU or a vehicle in its collision course • Softer acceleration/speed profile
Automated Valet Parking	• Reduced travel times for drop-off and pickup • Increased safety using additional sensor information. • Improved detection of VRUs • Reduced number of deadlock situations	• Time to park • Waiting time / time to return vehicle • Number of conflicts (e.g. due to an unforeseen obstacle) • Number of drive direction changes
Platooning	• Facilitate finding other vehicles as members for platooning • Extend the distance at which vehicles initiate towards platooning • Better anticipation on legacy traffic, traffic lights states etc. • Better inter-vehicle distance maintenance (e.g. using speed advice)	• Travel time • Number of platoon disruptions • Acceleration/deceleration level of vehicles • Cross intersections safely and without braking the convoy
Highway Piloting	• More streamlined and frequent detection of hazards • Improved accuracy of anticipating the hazards • Smoother manoeuvres when passing over or approaching hazards leading to comfortable and safer journey	• Detection reliability and rate • Accuracy of the location of hazards • Proper and timely reception of warnings/instructions in vehicles • Smoothness in longitudinal and lateral manoeuvres based on acceleration profile

5 Annexes

5.1 Definition of SAE levels

5.1.1 Introduction

The Society of Automotive Engineers (SAE International) is a standards development organisation about automotive and mobility matters. Although the qualifier 'International' appears in its name, it is clearly oriented towards the American market. Administratively, the main contact is in North America. Technically, for example, it uses a more Anglo-Saxon 'miles per hour' unit to measure speed, rather than the more international 'kilometre per hour'. However, SAE has developed standards in wide use across continents, such as the Vehicle Identification Numbers (VIN).

The SAE levels are extensively used as a reference in describing the autonomous vehicles. Recently, new automobiles announced on the market do use these levels as features (e.g. Renault Clio VI is announced to support certain 'Level 2' features such as adaptive cruise control).

Simultaneously with the development of the standard of SAE Levels, automobile manufacturers routinely advertise new proposals of norms that characterize autonomous driving. The concepts of 'Eyes off' vs 'Hands Off', the 'Electronic Horizon', are - few - norms that are touted by particular manufacturers. There is no direct relationship between the SAE levels and the norms.

SAE level is a classification of levels for driving automation. These levels have been standardized in SAE J3016 in 2014; the most recent version is dated June 2018 (J3016_201806)[53]. The J3016 standard defines six levels of driving automation, from SAE Level Zero (no automation) to SAE Level 5 (full vehicle autonomy). It serves as the industry's most-cited reference for automated-vehicle (AV) capabilities.

5.1.2 Definitions

Let's define some concepts that are important in this section (according to SAE J3016):

ADS: Automated Driving System is the hardware and the software systems that sense and monitor conditions inside and outside the vehicle; this 'sensing' is based on the 'bouncing signal' principle: send a signal, measure time and record echo; it is used by radars, sonars, lidars and, to a certain extent, cameras. Its purpose is to identify perceived present and potential dangers to the vehicle, occupants and/or other road users and automatically intervene to help avoid or mitigate potential collisions via various methods. These methods include alerts to the driver, vehicle system adjustments, and/or active control of the vehicle subsystems (brakes, throttle, suspension, etc.).

DDT: Dynamic Driving Task defines all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints, and including without information:

- Lateral vehicle motion control via steering (operational);
- Longitudinal vehicle motion control via acceleration and deceleration (operational);

[53] SURFACE VEHICLE RECOMMENDED PRACTICE, SAE J3016, (R) Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, last revision June 2018.

- Monitoring the driving environment via object and event detection, recognition, classification, and response preparation (operational and tactical);
- Object and event response execution (operational and tactical);
- Manoeuvre planning (tactical); and
- Enhancing conspicuity via lighting, signalling and gesturing, etc. (tactical).

DDT fall-back is the response by the user to either perform the DDT or achieve a minimal risk condition after occurrence of a DDT performance-relevant system failure(s) or upon operation design domain (ODD) exit, or the response by ADS to achieve minimal risk condition, given the same circumstances.

ODD: Operational Design Domain defines the operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.

OEDR: Object and Event Detection and Response represents the subtasks of the DDT. That includes monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed. That also includes executing an appropriate response to such objects and events (as needed to complete the DDT and/or the DDT fall-back).

5.1.3 Levels

The Levels are defined hereafter:

- **Level 0** means that there is no driving automation. All performance is bound to the driver, no matter whether it exists an active safety system or not. The driver controls the entire DDT. An example of the simplest feature absent from Level 0 is the Anti-Blocking System (ABS), or Electronic Stability Program (ESP).
- **Level 1** means that there is a driver assistance. The sustained and ODD-specific execution is handled by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously). That is handled with the expectation that the driver performs the remainder of the DDT. An example of Level 1 feature is 'Cruise Control'.
- **Level 2** means that there is a partial driving automation. The sustained and ODD-specific execution is handled by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT. That is performed with expectation that the driver completes the OEDR subtask and supervises the driving automation system. An example of Level 2 feature is 'Adaptive Cruise Control'.
- **Level 3** means that there is a conditional driving automation. The sustained and ODD-specific performance is handled by an ADS of the entire DDT. That is performed with the expectation that the DDT fall-back-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately. A probable example of Level 3 feature is 'Emergency Braking'.
- **Level 4** means that there is a high driving automation. The sustained and ODD-specific performance is performed by an ADS of the entire DDT and DDT fall-back. That is done without any expectation that a user will respond to a request to intervene. An example of

Level 4 feature is the presence of 'A' button on the dashboard ('A' stands for automation); an alternative to 'A' button is the double click of the left lever.

- **Level 5** means that there is a full driving automation. The sustained and unconditional (not ODD-specific) performance is handled by an ADS of the entire DDT and DDT fall-back without any expectation that a user will respond to a request to intervene. There is not known Level 5 feature deployed on automobiles.

5.1.4 Communication systems in the SAE classification of Levels

The use of the Internet of Things (IoT) is of potential benefit to realize the task of autonomous driving.

At the strategy level (outside the SAE classification), the automobile connected to the Internet benefits enormously from the planning and booking of autonomous shuttles.

At the tactical and operational levels, a bidirectional communication system (TCP/IP messages, DSRC transport, ITS-G5 and related) – as opposed to the existing 'bouncing signal' sensing systems (radars, sonars, lidars) – may offer huge advantages to the realization of AD tasks. The advantages are issued mainly from the practically infinite semantics afforded by a cooperative exchange of messages. Rather than measuring a distance with a lidar prone to visibility error conditions, a rich radio message exchange of the form 'are you close to me? No, I am at 30m' may significantly improve the flexibility of applications realizing autonomous driving.

At the current state of development, the J3016 standard is independent of the capability of an autonomous vehicle to rely entirely on communication system for sensing, rather than relying on radars, lidars, cameras and sonars. It is however a communication system that is used for realization of platooning in Versailles PS (and not the radars, lidars, sonars, cameras).

It is possible to define new levels:

Level1-C: it is Level1 with the addition of support of a communication system (TCP/IP messages, DSRC transport, ITS-G5, IEEE 1609).

Level2-C: it is Level2 with the addition of support of a communication system (TCP/IP messages, DSRC transport, ITS-G5, IEEE 1609).

Level3-C: it is Level3 with the addition of support of a communication system (TCP/IP messages, DSRC transport, ITS-G5, IEEE 1609).

Level4-C: it is Level4 with the addition of support of a communication system (TCP/IP messages, DSRC transport, ITS-G5, IEEE 1609).

Level5-C: it is Level5 with the addition of support of a communication system (TCP/IP messages, DSRC transport, ITS-G5, IEEE 1609).