How IOT based Automated Driving can help cities to reduce Air Pollution

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Abstract

This paper looks at the relation between IOT (Internet of Things) assisted automated driving and the challenge of air pollution causing mobility access restrictions for European cities. After a brief discussion of the EC regulatory framework, the need for additional pollution data will be described suggesting to shift existing single-source air quality models to 2D and even 3D measurement platforms for improved air quality monitoring. Finally, the role of telecommunication and ICT industry for automated driving solutions will be elaborated, following by the description of pilot services contracted in the Horizon 2020 EU funded Autopilot project, currently under project execution in several European large-scale pilot sites.

1.Introduction

When it comes to air pollution, many European cities are facing serious challenges to comply with existing environmental laws and policy regulations. NO_2 and PM measurements regularly exceed WHO thresholds and policy makers started to implement Clean Air master plans to reduce air pollution. Road traffic is reported to be responsible for almost 40% of emissions [1] and clean air measures vary from driving bans to low emission zones and city tolling. Giving the importance of mobility and public health for European citizens, many innovative concepts for low emission mobility are in the development phase, e.g. the EU funded Autopilot project with a focus on IOT based Automated Driving for electric vehicles.

It is assumed that Automated Driving will support cities to give better urban access for commuters when looking for Park & Ride facilities as well as for alternative shuttle services and last mile logistics. For example, air pollution could be reduced by measures of offering combined tickets for commuters including free parking. In case of exceeding certain limits of air pollution, the public transport fee would then be reduced, even including Park & Ride access for car drivers. In 2017, the German Ministry of Transport and Digital Infrastructure (BMVI) launched a One-Billion-Euro Program to help German municipalities [2] to implement clean air master plans and cut down NO_2 emissions until 2020 to become compliant with EC air quality regulations again, thus avoiding any type of legal actions already threatened by the European Court of Justice.

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2.Environmental risks and mobility challenges for urban transport systems

One of the key problems in cutting down traffic related NO_2 emissions lies in the complexity of finding strategic priorities for reduction measures. To derive strategic measures for this target, Newtonian Physics gives a mathematical approach by applying the energy equation for an object in motion. The equation for fuel consumption in units of [Liter/100km] is written as

$$(1)\Phi(v>0)=\eta b_e \frac{\int_o^T (F_{acc}+F_{brake}+F_{roll}+F_{air}+F_G)v(1s)dt}{\int_o^{T'} v(1s)dt}$$

$$(2)\Phi\left[\frac{Liter}{100km}\right]=\Phi(v>0)+\Phi(v=0)$$

$$(1.a)F_{acc}=m*\frac{dv}{dt} \quad ,dv>0$$

$$(1.b)F_{brake}=\beta m*\frac{dv}{dt} \quad ,dv<0$$

$$(1.c)F_{air}=\frac{\rho}{2}*A*c_w v^2$$

$$(1.d)F_{roll}=mg\mu$$

$$(1.e)F_G=mg*\sin(\alpha)$$

$\eta = engine\ efficiency\ [\%],\ b_c = fuel\ value\ [\frac{MJ}{Liter}]$

$m = total\ weight\ [kg], v = speed\ [\frac{km}{h}], \beta = propulsion$

$\mu = friction\ coefficient, g = acceleration\ of\ gravity$

$\rho = air\ density, A = Cross\ sectional\ area, c_w = drag\ coefficient$

$\alpha = gradient, T = driving\ time$

$T' = Travel\ time\ to\ reach\ the\ reference\ distance, usually\ 100km$,

For further details see reference [3]. Despite of the numerous input parameters in equation 1 and 2, there are 3 important categories to mention:

a) time-dependent parameters per trip (speed, acceleration, travel and driving time, gradient, standstill);
b) vehicle depending parameters (weight, cross sectional area, drag and friction coefficient, engine efficiency and fuel value);
c) physical constants (acceleration of gravity, air density).

This leads to the possibility of measuring the energy consumption per vehicle trip by collecting GPS speed profiles per second with the help of a simple smartphone. By comparing these speed profiles with well-known and standardized driving cycles, e.g. the European Driving Cycle, and reference vehicle configurations, the deviations of driving resistances as stated in 1.a) to 1.e) can be analyzed in [%]. This helps to better understand the cause for low and high fuel consumption occurring during a trip, i.e. in complex urban road conditions. As shown in Figure 1, such an analysis per trip enables fleet operators to cut down fuel costs and emissions by having a complete picture of all influence factors for emissions at the same time, which are

1. Analysis of Driving Behavior leading to better "predictive driving and braking",
2. Analysis of Road Types leading to better "traffic-optimal speed selection" and “routing plans”
3. Analysis of Traffic Conditions leading to "congestions minimized tour plans".

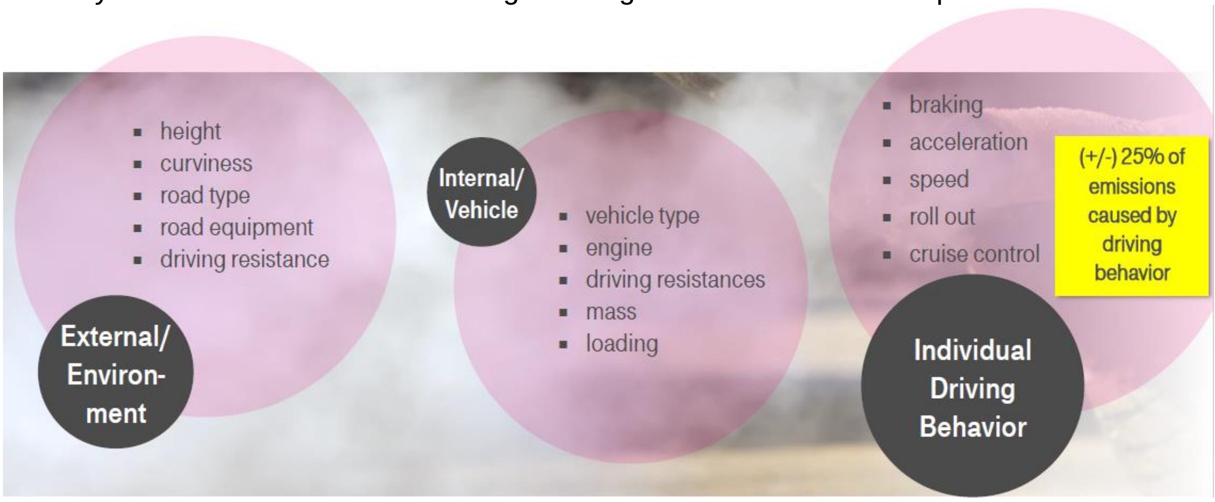

Figure 1: Influence factors for NO_2 emissions in vehicle based road traffic

In the years 2008 to 2012, T-Systems developed and implemented a system to operate such strategic fuel reduction measures as Cloud based service for Logistics Service Operators, which was funded by Deutsche Telekom AG and the German Federal Ministry for Economic Cooperation and Development (BMZ) under the project name Low Carbon Mobility Management (LCMM) and deployed as showcase during the Shanghai 2010 EXPO. Thus, LCMM became a lighthouse project for low carbon mobility under the climate policy umbrella of Sino-German Ministries of Transport implementing projects to cut down Greenhouse Gas (GHG) emissions in the transport sector, see [4].

From a policy perspective, all vehicle, road type and traffic management centric measures to reduce fuel consumption in the transport sector are of high importance due to the fact that every saved liter of fuel is directly proportional to CO_2 and NO_x reductions. On the other side from commercial fleet perspective, transport and logistics service operators benefit from reduced operational expenses (OPEX) linked to fuel costs. After the successful pilot implementation with two Logistics Service Providers in Beijing and Jiangsu (China), LCMM was rolled out in Europe in several logistics R&D projects [5] and is now accepted for 2019 ETSI standardization in the Working Group Nomadic Devices, which is part of the Horizon 2020 project AEOLIX (see www.aeolix.eu).

Besides efforts towards standardization of carbon footprint monitoring by the use of nomadic devices, the first Chinese Logistics Service Providers (LSP) decided to operate LCMM directly within their fleet operation centers. Since 2015, more than 200.000 hours and 10 Million km of fleet operations were reported by GPS smartphones leading to reduction measures of eco-drive training and optimized tour planning. This was achieved by weekly scoring reports and applied Big Data analysis made available directly to the operating staff which had regular dialog with the drivers delivering goods. After implementing LCMM for the first Chinese LSP, an average of 16% fuel and carbon savings per ton of payload was found in the financial systems, thus supporting the sustainability and efficiency targets of the LSP user.

As LCMM will be submitted within Aeolix for ETSI standardization, the procedure of applying energy equation 1 and 2 as KPI for impact evaluation can be considered helpful for upcoming new mobility projects such as Autopilot, an IOT based Automated Driving project within the H2020 R&D framework.

3. The holistic approach: From single to multiple source analysis of air pollution in urban transport mapping complex cause and effect phenomena

With regards to air pollution, data collection and KPI impact evaluation, e.g. for Sustainable Urban Mobility Plans (SUMP), play a crucial role to find out the effectiveness of actions taken by a municipal government in the context of cutting down NO_2 emissions according to the environmental policy regulations for Public Health as agreed by all EU member states. The key challenge remains the reliability of pollution measurements as the number of measurement stations is limited and extremely sensitive to the space-time model of detection.

Usually, legal actions by the European Court of Justice are based on measurement stations authorized by Environmental Agencies in the member state which signed the 2008 EC Environmental regulatory framework. Violations lead to legal investigations and in worst case to fines based on a corresponding court decision. Nevertheless, the baseline for all legal and political decisions are single source measurements located in very limited space and time under control and authorization by Environmental Agencies.

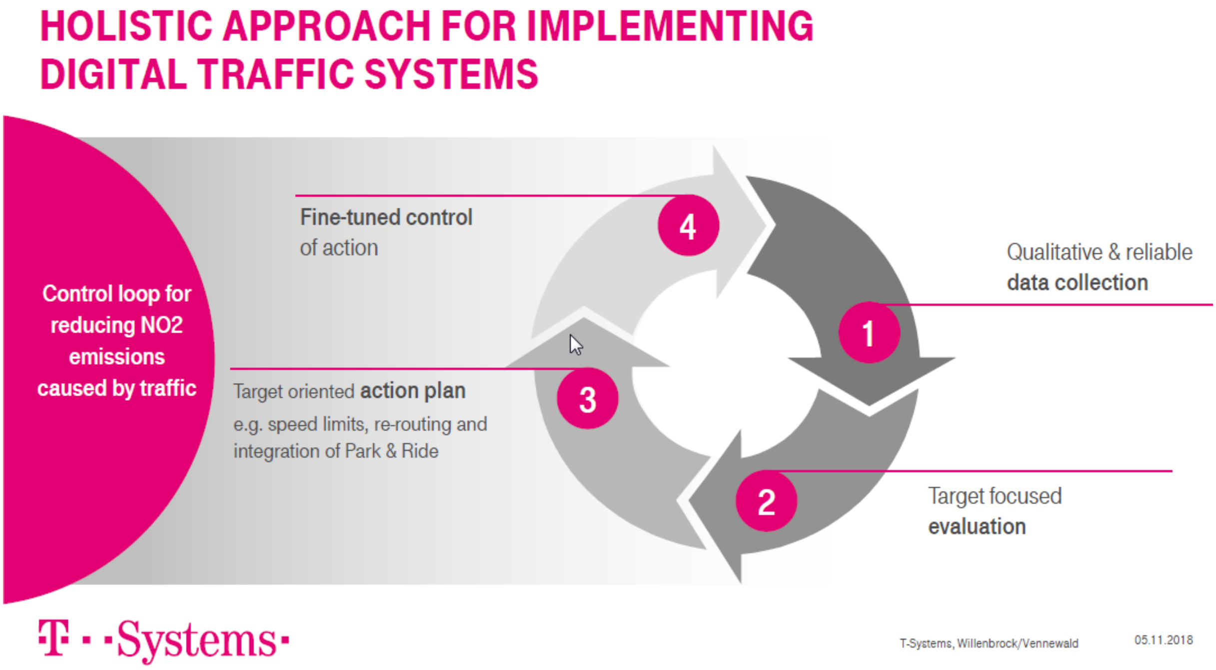

Figure 2 Control loop for reducing NO2 emissions caused by road traffic

Given the complexity of phenomena influencing the overall emissions in an urban environment a fine-tuned control loop (see Figure 2) to cut down emissions is required. In such a control loop the first Phases 1 and 2 include the realistic planning and definition of reduction targets. For this purpose, existing emission modelling is recommended to be expanded by road network data delivered by Public Authorities, mobile speed data collection from cellular telecommunication networks and Floating Cars from urban logistics fleets and Public Transport operators. When creating the appropriate data fusion algorithms, 1-dimensional single-source modelling can shift to 2-dimensional multi-source modelling. For such an approach Automotive Industry has a lot of useful mobility data to share with Public Authorities and 20 years of project experiences along TMC standardization for Dynamic Navigation Systems is a good examples of innovative service evolution, see [7] and [8]. Additionally, first experiences from using Earth Observation satellite data for the integration of ground-based air quality measurements by Copernicus atmosphere data merged via data fusion towards 3-dimensional air quality information started and can be considered as the next exciting innovation path for air quality services in the near future [9].

Compared to the single-source approach, such an innovation pathway towards 3-dimensional analysis of air quality offers long-term control of achieving the political emission reduction targets which are inside the European Union very strict and therefore difficult to achieve. Nevertheless, one economic objective of the EU-wide strict regulations was to foster industrial product innovation bringing the necessity of close cooperation between automotive and telecommunication industry with municipal traffic and environmental authorities. A schematic illustration of the holistic approach is shown in Figure 3.

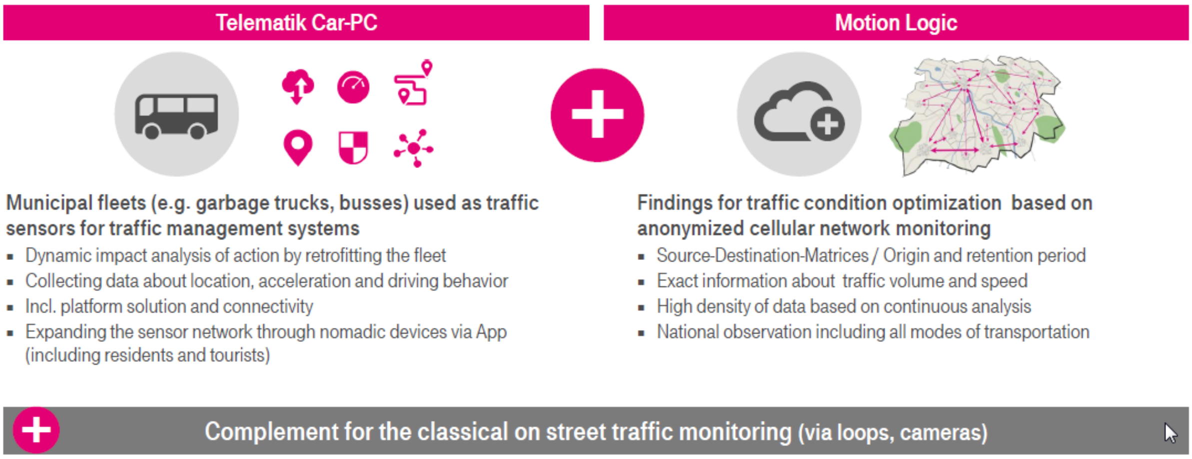

Figure 3 Extended data collection strategies based on multi-source integration of fixed and mobile data from Floating Cars with telematics devices as well as anonymized cellular speed profiles from telecommunication networks

In Figure 4, some typical clean air initiatives are listed ranging from speed reductions, access restrictions, combined public transport ticketing strategies or low emission concepts for urban goods delivery. Each of these measures must be controlled by municipal decision makers in an authorized manner to find out long-term effectiveness or political need for changing or adjusting a clean air action plan. Therefore, the shift from single to multiple source analysis is needed, a process which took place in weather forecast by establishing the science of synoptic meteorology with the introduction of 3-dimensional weather modelling through synoptic evaluation of merged stationary and satellite data sources. For the similar complex task of NO_2 reduction, the shift to 3-dimensional data analysis of air quality is promising as it might lead to the same quality in forecast models for clean air action plans. This is illustrated in Figure 4, where one can see the different building blocks for such a 3-dimensional data analysis and control loop methodology suggested for European municipalities.

Before progress towards synoptic clean air modeling can take place, new mobility data sharing platforms have to be built in close cooperation with data driven business models. This is the same for Automated Driving when being extended to larger areas of road segments in cities. Here, IOT sensor data exchanged with high performance cloud platforms is assumed to play a key role for IOT based Automated Driving. In 2016, the European Commission funded five Large-Scale Pilots (LSPs) on the Internet of Things ([10]). The AUTOPILOT project was selected as Pilot 5 for autonomous vehicles in a connected environment. The EU reviewers wanted to showcase Automated Driving in complex road conditions with the support of IOT and the perspective of attractive mobility use cases with positive impact for clean initiatives. Mobility data sharing is one of these use cases.

Actions:

- **Reducing** speed (dynamic 80/60/40/30)
- (Voluntary) **switch** to public transportation at P&R-spots
- Condition based traffic guidance, route-optimization based on public recommendations
- Improving **P&R accessibility**
- Optimizing the search for parking spaces including public transportation ticketing
- Dynamic allocation of **parking lots** as part of regional park guidance systems
- Including corporations (ride sharing, job-ticketing, dynamic provision of parking lots, ramp control of goods transportation (Logistics, E-couponing)

+ Motion Logic =
Source-destination-matrices for connecting the outback to public transportation and logistics

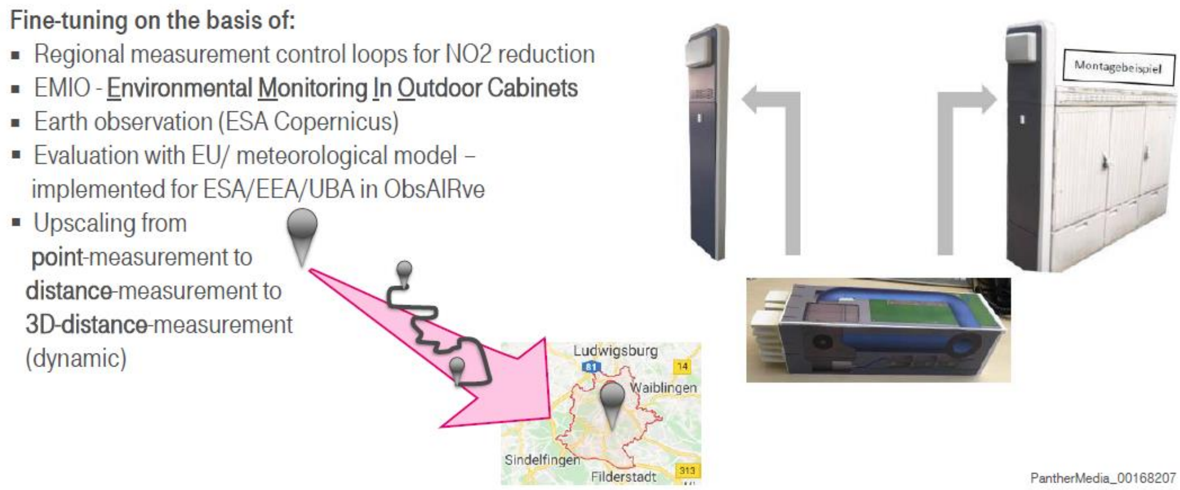

Figure 4 From 1-dimensional to 3-dimensional air quality measurements, including NO_2

4. The role of Telecommunication and ICT within the Autopilot project: balancing mobility needs with access restrictions for citizens caused by clean air initiatives

After describing the need of multiple source analysis for municipal decision makers when implementing clean air master plans including mobile data from vehicles and their speed profiles along the road network, the role of telecommunication and ICT industry for IOT assisted Automated Driving services needs to be introduced. The Low Carbon Mobility service in Figure 1 is based on mobile communication and needs real-time data provisioning (connectivity). Compared to this service the control loop from Figure 2, is running on a political decision base and is independent of communication technology when using stationary measurement stations alone. Nevertheless, given the importance of mobility access restrictions for commuters and urban citizens the reliability of data collection and the effectiveness of the Clean Air policy measures shows that the ad-hoc availability of data helps municipalities to increase transparency and to better convince citizens of taken measures. With the upcoming 5G technology and the standardization behind it, complex data exchange between sensors, data centers, road side units and vehicles can be managed and guaranteed for users and mobility services.

As shown in Figure 5, the road side infrastructure (traffic lights, VMS, etc.) can be connected to the vehicle either by I.T.S.-G5 or LTE-V, complemented in the next years by cellular (C-) I.T.S., just depending on the different local implementations. Additionally, mobile communication data, e.g. from Motionlogic, supports this set-up for both, LCMM and Automated Driving.

Within the Horizon 2020 Autopilot project [10], all active pilot sites will exchange data both from road side units or via cellular networks. Mainly, such hybrid communication approach is used because Autopilot wants to showcase services and business cases in which innovative mobility services are operated in complex road conditions of several kilometers length but is not limited to service such as automated valet parking in limited geographical space of some hundreds of meters, where only road-side units with point-to-point vehicle-to-infrastructure communication (V2I) are available, e.g. car parks. Figure 5 also illustrates that from the telecommunication network side, mobile edge computing (5G MEC) is under investigation for car-to-car communication for low latency reasons.

It is well-known that automated driving will reduce carbon emissions, but this qualitative impact is difficult to quantify in certified KPI's needed for SUMPs. And this is the link to standardized carbon footprint monitoring services such as LCMM used in Aeolix. With the help of standardized Big Data analysis along the energy equations 1 and 2, the effectiveness of IOT assisted Automated Driving can be evaluated and the measurable impact analysis allows mobility service providers to quantify the amount of NO_2 and GHG savings achieved by the deployment of innovative new services.

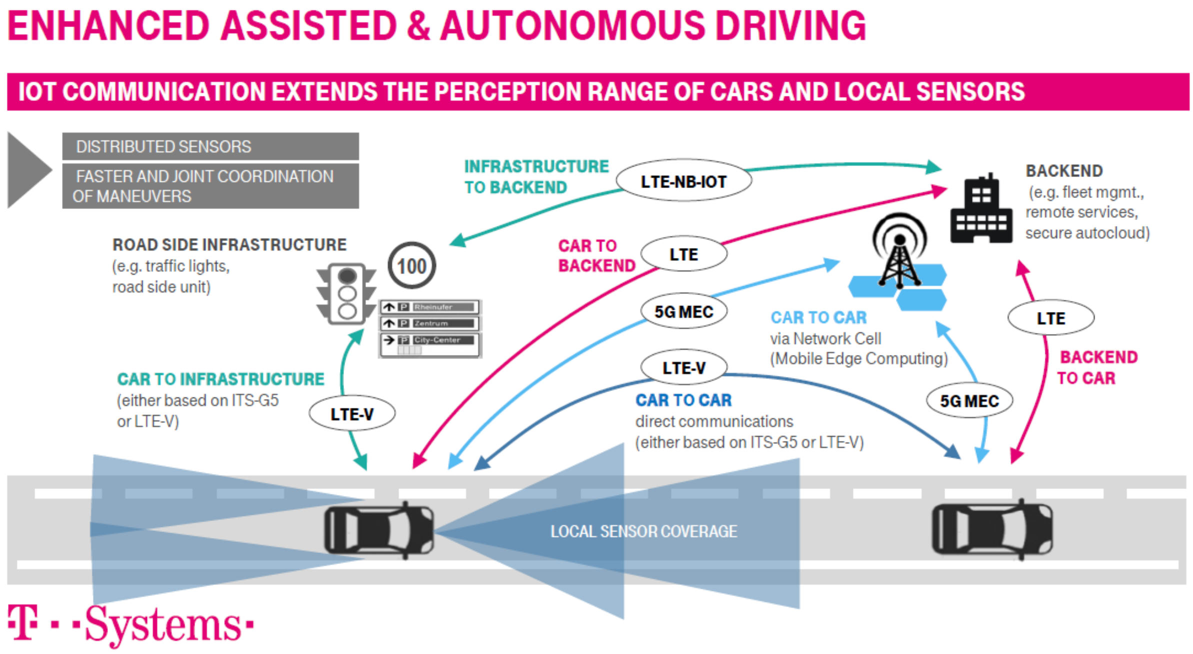

Figure 5 Schematic overview of the different data exchange objects relevant for IOT based Automated Driving service deployment

Within the Autopilot project, environmental impact is of special interest for all mobility services under development ([11]). Figure 6 shows this in exemplary manner. The Versailles pilot area is illustrated on the map showings that tourists can book AD vehicles and drive either by themselves (inside the city of Versailles) or in an automated manner (inside the park of the castle). After dropping the vehicles off somewhere inside the city, a manned lead vehicle will collect the AD vehicles in a platoon and bring them back to the parking space of the rental car service provider. This way, the mobility service provision is directly linked to tourism, which is foreseen to massive growth rates shown in Figure 6. It is assumed that the number of tourists visiting Europe could increase from 609 million visitors in 2015 up to 1.8 billion visitors in 2030, which would be an increase of more than 300%. As tourists generally are not familiar with the road network and local traffic conditions, Automated Valet Parking or City chauffeur rental car services are considered as attractive service offering for a touristic venue in any European country.

Figure 6 The Versailles Autopilot test site for Automated Valet Parking

The idea of bridging such innovative Automated Driving services with holistic control loops for NO_2 reduction targets, including automotive and telecom combined mobile data collection for environment-sensitive traffic management tasks presented in chapter 3, seems to open the door for new data markets. As the quality of urban transport modes and metropolitan air quality decrease or increase in a synchronized manner, the holistic approach and research for Automation seems to be natural way of innovation, municipalities are looking for. Here, the Autopilot project is a good example of bringing together industry, research and public-sector stakeholders into one project and can be considered as lighthouse project for innovative mobility services.

5. Summary

Nowadays, mobility access restrictions for low emission zones are widely spread among European cities, mostly initiated to comply with the strict air quality regulations of the European Commission. Nevertheless, the effectiveness of all air quality master plans is easily questioned by the general public as long as only single source air quality detection is in practice, because this makes air quality measurements in complex urban environments quite incorrect and sensitive to statistical and rather local phenomena. Therefore, additional mobile and telematics data sources from vehicle fleets and mobile communication networks are recommended to shift 1D single source detection towards 2D or even 3D air quality maps. In this paper, it was elaborated how such an approach could help clean air initiatives similar to the quality improvement which took place in weather forecast by moving towards synoptic meteorological models with the help of Satellite data sources. Once the data sources are more reliable, European municipalities will have to implement innovative mobility services compliant with improved air quality detection. This can include intermodal shift and extended Park-and-Ride offerings, in especially for commuters. In the paper it was shown that IOT assisted Automated Driving, , is an excellent complementary technology for Cities looking for low emission mobility services as it allows to establish flexible car sharing or rental car offerings. In the Horizon 2020 project Autopilot, these offerings are currently under investigation in several large-scale pilot sites and linked to tourists venues, with French City of Versailles being one of them.

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