A.T.2.1

DESIGN AND DEVELOPMENT OF TOOLS SUPPORTING PARKING REGULATION SCHEMES SELECTION AND IMPLEMENTATION

Deliverable D.T 2.1.2 –*Overall design of the Parking Regulation Schemes and related Data Management System*	Final Version 06/2018

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1 Introduction

This report is a part of the SOLEZ work package WPT2.1 that deals with smart parking innovative Tools for the planning of low carbon mobility policies for city centers.

Its significance is given in the introduction of the previous project report D.T2.1.1. As outlined in that report, the work package WPT2.1 is divided into tree activities: (i) transnational review and user requirements analysis for smart parking solutions, (ii) **Overall design of the Parking Regulation Schemes and related Data Management System**(iii) - Smart Parking supporting tool developed

While the subject of the previous report D.T2.1.1 was activity (i) (i.e. Task 2.1.1), the subject of this report is activity (ii) (i.e. Task 2.1.2), and other activities are the subject of forthcoming project reports.

1.1 Global objective of parking regulation scheme and data management system

The aim of SOLEZ parking regulation scheme is to provide a comprehensive approach to introducing a smart parking system in city centrech and its urban areas to improve the planning of low carbon mobility connected with traffic regulation and access restriction schemes (including LEZ, LTZ, etc.) in the Functional Urban Areas.

This aim is motivated by the need of stakeholders, urban planners etc.to have the plan how to **use new parking tool** to regulate individual car traffic in city central areas and adjacent conurban areas based on real information on occupancy of street parking, important parking areas, air pollution in the area and up-to-date information about traffic. In particular, the document focuses on the implementation of regulation scheme in places where there is a long-term problem of interaction between parking and traffic mainly due to implementation of ZTL.

The theoretical basis of the regulation scheme is based on the fact that in exposed locations up to 30 % of traffic congestion in cities is caused by vehicles trying to find a free parking space (Hui Zhao, 2012).

The assumption is that if the driver is provided with information about the current situation where it is possible to park and how to drive in a problematic location, the number of vehicles that are looking for a place to park and "cruise" will be reduced. Building on the outputs of the innovative systems that provide this useful data, the public administration will be provided with information from the continuous collection of data on the times and occupations of parking areas, parking spaces and vehicle movements in individual streets of the city or locations with frequent traffic congestion and subsequent breaching of air quality limits.

There are some basic principles behind every successful implementation of smart parking which we put together in this parkign regulation scheme document and was primarily divided into

(i) **Analytical part** helping to select the proper related parking control systems, (ii).**Design part** of Data Management System and (iii) Parking Regulation Scheme **Checklist for pilot testing.**

Chapter 3: provides an overview over the SOLEZ parking regulation scheme

Chapter 4: explain the concrete steps how to analyze location and desribes what methods are available for quantification of vehicles seeking a place to park in location

Chapter 5: desribes DMS part 1: Implementation and integration into information and parking control systems

Chapter 6: desribes DMS part 2: Identification of the sources of pollution and their detection

Chapter 7 explain cases and phases to implement a SOLEZ Parking regulation scheme.

2 Terminology

Sensors network – a group of sensors bound into one whole, ideally within a single IoT communication network having a common aim to detect a certain phenomenon in a wide area

IoT – Internet of Things, interconnection of single devices by internet technologies without active participation of a human being. The devices can be vehicles, home utilities, wearables or various sensors that exchange information among the others or collaborate

LORA – technology of radio modulation for communication of IoT devices with low power consumption; it is a patented technology originally developed by the company Cycleo (Grenoble, France) using license-free sub-gigahertz radio frequency bands like 169 MHz, 433 MHz, 868 MHz (Europe) and 915 MHz (North America). There are two protocols above the physical layer: LoRaWan and Ultra narrow band

SIGFOX – ultra narrow band technology working that enables communication using the Industrial, Scientific and Medical ISM radio band which uses 868MHz in Europe and 902MHz in the US. It utilizes a wide-reaching signal that passes freely through solid objects, called "ultra narrowband" and requires little energy, being termed "Low-power Wide-area network (LPWAN)". The network is based on one-hop star topology and requires a mobile operator to carry the generated traffic. The signal can also be used to easily cover large areas and to reach underground objects

NB IoT – narrow band radio technology, standardized by 3GPP, using LTE communication and devoted mainly to indoor applications

MaaS – Mobility as a Service is a concept integrating all the available transport modes within a region to enable to combine travelling by all the available means of transport. It is an extension of integrated public transport systems by new sharing concepts (car sharing, bike sharing, car pooling atp.). In ideal case the regional public transport organizer (or a city or a region) enable travellers to pay monthly payments for all the used means of transport within a single invoice

Smart parking – concept building on continuous occupancy monitoring of parking lots to enable to support technologically city parking strategies, implement demand based pricing (the price is based on the demand), monitor and enforce time limitation or payment for parking or to motivate drivers to park in parking houses (off street parking) or find a free parking space much easier

Traffic Burden Monitoring System, TBMS – low cost monitoring system providing wide area monitoring of a zone regarding actual or longterm traffic burden and air quality levels in the resolution of a street, suitable for analytical parts of Sustainable Urban Mobility Plans (SUMP) or Air Quality Action plans, comprising of two parts: traffic flow monitoring per street and monitoring of air quality with AQ ITS stations

Air Quality station (AQ ITS-S)) – station for measuring air quality used for the long-term monitoring of air quality; with regard to the supposed source of traffic pollutants it should be capable of stable and accurate measuring of the concentrations of nitrogen oxides using the reference method (EN 14211), that is, Class C stations. For the purpose of refining the information, the station may be extended by a particle count instrument operating on the nephelometry principle (class B stations) and a benzene concentration measurement device, again operating on the reference method (EN 14622-3) (Class A stations)

M2M – (communication machine-to-machine) mutual communication among the machines; it enables to communicate wireless or wired interconnected devices that have the same or similar possibilities without any human operation

Cloud – Cloud computing is an information technology (IT) paradigm that enables ubiquitous access to shared pools of configurable system resources and higher-level services that can be rapidly provisioned with minimal management effort, often over the Internet. Cloud computing relies on sharing of resources to achieve coherence and economy of scale, similar to a utility. It can described also as a provision of services or programmes by servers accessible by internet as the users can access them remotely, e.g. by web browser, email client or a database

Key performance indicators KPI - a type of performance measurement. KPIs evaluate the success of an organization or of a particular activity (such as projects, programs, products and other initiatives) in which it engages.

3 What is SOLEZ parking ragulatin scheme

The use of clever ICT tools is one of the key elements of **a SOLEZ parking regulation scheme**. Such a tool can, but does not have to be, based only on **parking space occupancy detector**. It can be one part from whole **innovative senzoric network**.

When talking about **an innovative sensor network** it is about introducing especially networks of senzors monitoring the occupancy of parking places in locations and network of monitoring stations for air quality measurement that can provide the data to transport information, dispatching or, control systems "Data management system"

Which detection technology you will choosed depends on your budget, monitoring plans, the degree of financial and technical support by external partners and obviously your stratetegic mobility plans

A SOLEZ parking regulation scheme also takes into acount the latest development of new technologies and communications networks. The latest experiences shows that it can be very difficult for the representatives of cities, regions and government to orientate well and choose suitable, proven and reliable solutions in this environment.

Therefore this document addresses primarily to provide comprehensive and validated information and advice on how to access these technologies and assess their suitability, how to choose between different technologies with regard to the overall transport concept of cities and their urban areas. At the same time, it is important to continuously monitor the continuous and rapid development of ICT technologies and to maintain the development of transport information and control centers.

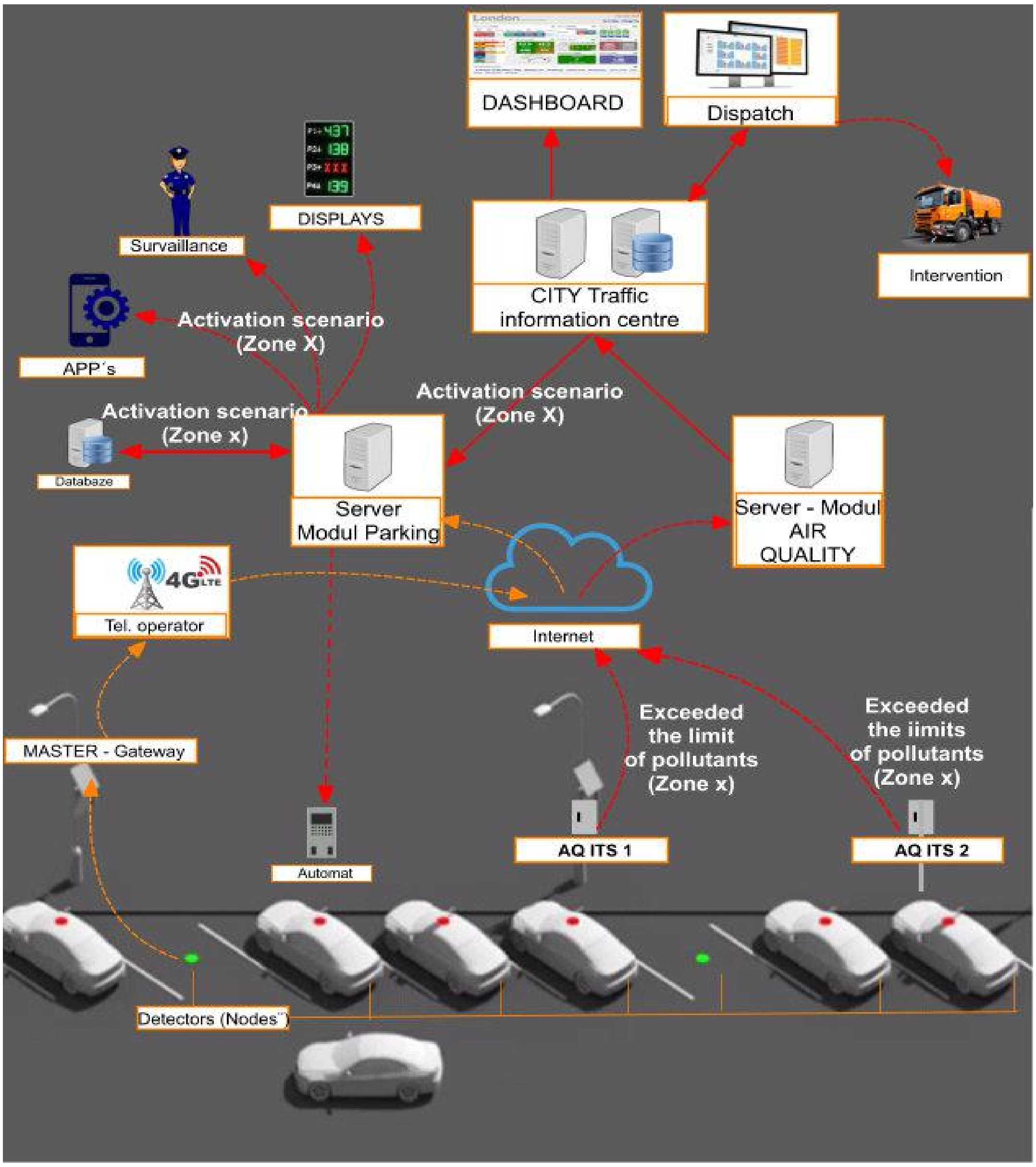
The architecture below define overall concept of SOLEZ parking regulation scheme and demonstrates the basic structure.

The core of the regulation scheme is of the following elements:

- ✓ the sensor networks to collect the important information about traffic load or air quality by default,
- ✓ senzors monitoring the occupancy of parking places
- ✓ senzors monitoring air quality
- ✓ centralyze SW modul

The innovative contribution consists in **integration of data from various sources** etc. senzors monitoring the occupancy of parking places, senzors monitoring quality, into one centralyze SW platform, adjustable by any party or municipality, that is able to accept data from different suppliers in the standardized EU data format, DATEX II. The common description of parking places in the standardized way can contribute to the delivery of global services of navigation in EU cities to any driver.

Last but not least, the municipalities may come up with completely new motivation or gamification schemes that ICT technology allows with the aim to increase acceptability and reducing adverse side effects of LEZ and other access restriction policies.



Scheme 1: Concept of Solez parking regulation scheme

3.1 Target audience

This document is perfect for raising awareness of relevant stakeholders. It explains a general principles behind such preparation of smart parking system, gives step by step advice on how to prepare it location and provides all kind of technical information.

The relevant stakeholders are

- City officials (heads of transport departments, town planners, property managers, etc.)
- Regional administration officers
- Public transport operators and transport companies (potential future MaaS operators - Mobility as a service providers)
- Traffic managers (including rail) and other broad professional public:
- Traffic engineers and design offices
- Academic and Researchers

Although this document mainly is supposed to strengthen local low carbon mobility policy, it is essential to pay attention to the broader issue of **integrated urban transport policy**, since an **effective parking scheme cannot be pursued on its own**. Any parking scheme should be developed as a part of the broader urban sustainable transport policy and mobility concept.

To maximize profits from the deployed technologies the action plan for FUA deployment should incorporate parking regulation scheme. The action plan should tackle the inner city traffic as well as outer city traffic (commuting traffic motivation to exchange the mode in the hinterlands). This document describes various use cases (Chapter 7)to tackle both issues which are to be tested by SOLEZ partners´ pilots.

4 Analytical part and selection of the proper PRS

This chapter describes specific steps resulting in efficient implementation of a smart parking tool[1] (sensor network). The first step involves **specification of an area** and subsequently its characteristics so that suitable detection technology of the Smart parking tool for specific area can be selected on their basis. Next step is to set **the objectives** of considered sensor technology or combination of technologies. This technology shall be always designed and subsequently implemented only after a set of **user requirements** is specified ("what do we expect from the system").

4.1 Selection locality with the problem on the interaction between parking and traffic

4.1.1 General characteristics of the locality

The first step relates to selection of a location or locations where it is reasonable to assume that the smart parking tool will result in desired effect which is **mitigation of negative impacts of interaction of moving and stationary traffic** where critical problems comprise lack of parking places and that the drivers are not informed sufficiently about free capacities´ availability and therefore search for a parking places in an exposed location. Whereas already approved urban strategies are crucial for location identification, it is necessary to first analyze overall mobility status from a global perspective and to follow with subsequent incremental steps as mentioned in the following steps.

A) Strategies

Implementation of the sensor networks with the objective of improving interaction of moving and stationary traffic must be consistent with existing urban and sub-urban strategies. They comprise e.g. Strategic or land-use plan of a city, ideally extending beyond borders of its territory, Sustainable urban mobility plan (SUMP), General transportation plan, Air Quality Action plan, Traffic telematics plan, Implementation plan of the Internet of things (IoT) network.

These strategies specify general objectives and usually define zones with common rules for transport limitations (i.e. 30 km/h zones, regulation of resident and visitor parking, low-emission zones, pedestrian zones etc.).

These zones impose needs **to offer parking capacities (e.g. P+R, P+G etc.) in adjacent locations** with the option of transfer to alternative means of transport.

1 When talking about a smart parking tool, it is about introducing an innovative sensor network especially networks of detectors monitoring the occupancy of parking places

It also brings along the need to provide real-time information on parking capacities ´ occupancy with the option of navigation to the parking places. Moreover, there is also further need of linking the information with the PT information systems, arising within the context of transfer to the public transport. Set of all this information can be acquired by means of sensor networks´ implementations in these and adjacent locations.

B) **Significant spots in an operative area**

As huge demand arises for parking places in important/attractive city parts and their adjacent areas, significant socioeconomic roles of these areas must be taken into account. From the transportation perspective, they are **existing or new transport nodes** (e.g. in promoting development of polycentric cities). From the municipality development perspective, they are **city centres or places of historic or cultural heritage**. In terms of businesses and quality of life, they are the locations characterized by **high pedestrian movement** (e.g. shopping centres, offices, post office etc.). The significant spots are especially suitable for the sensor network implementation.

C) **Geographic conditions of an area**

Attractiveness of spots with regards to parking is determined also by geographic conditions of an area. Elevation and topography are important to determine the locations where interaction of moving and stationary traffic causes pollution. These are e.g. geographically given bottlenecks, i.e. bridges or slopes of city hills. Because of their positions, these locations constitute important traffic attractors and as such, they require the municipal corporations to execute regulatory interventions based on availability of data on vehicle movement and air quality.

D) **Spots with poor traffic conditions or poor air quality caused by traffic**

Based on the register of available data on traffic flow rates in a given area, it can be evaluated where the transport network capacity becomes reduced throughout the day. Based on this evaluation, the locations can be specified where the following is to be monitored:

- Measures of monitored pollution parameters and noise
- Interaction of moving and stationary traffic (monitoring of the vehicles heading “nowhere“, only to unknown parking place)

Data on traffic flow rates can be sourced from:

- Transport centres (traffic surveys, directionals, FCD data, analysis of big data from the mobile phone signal networks etc.)
- Traffic sensors (cameras at the intersections, induction loops, strategic detectors etc.)

This step is related to analysis of existing sensor technologies and creation of architecture of cooperating subsystems that form parts of selected architecture[2] of complex system solution in a municipality/city.

4.1.2 Analysis of the locality in relation to the infrastructure

Each implementation must include more specific characteristics of a selected location, especially in order to enable selection of suitable sensor technology for a given location. Besides, it is generally true that the efficiency of investment into sensor technologies is guaranteed if they are applied in a blanket manner.

Subsequently, it is possible to interconnect data on vehicle movement with data on stationary traffic (parking lot occupancy through control systems, regulation based on pollutant concentration).

It is especially necessary to monitor the following parameters/aspects:

A. **From the perspective of existing parking status in a specific area**

In the first place, it is necessary to do repeated daily and nightly survey of parking drivers´ behaviour in a specific location. Particularly these parameters of a specific monitored location shall be analyzed:

- **Analysis of existing organization level for stationary traffic** which shall comprise assessment of payment conditions´ effectivity including technical support and effectivity of repressive measures upon violating the parking terms. Possible modification or more precisely optimization of existing parking capacities´ configuration shall be also assessed. At this point, it should be noted that increase of parking capacities in a city centre results in increased traffic flow rate (traffic induction); therefore, establishment of new parking capacities shall be preferably considered outside of central areas.

2Architecture is general concept in which the system is interconnected logically, physically, organizationally and through data. Architecture enables handling the system from the perspective of open interfaces from and into it.

- **Analysis of transportation relations:**
  - amount of commuting vehicles (individual transport gradient)
  - analysis of on-street parking (occupancy, turnover)
  - acceptation of payment and other conditions (proportional representation of non-paying users, adherence to paid parking period etc.)
  - amount of vehicle journeys to a centre (residents of the suburbs, residents of other municipalities/cities, tourists)
  - amount of resident journeys within a city (resident gradient)
  - capacities of residential parking in an urban area (amount of illegal parking places, amount of vehicles parking on a given street)
  - amount of goods vehicles in a centre and delivery periods
- **Analysis of congestion development in entire operative area.** Traffic data from signal-controlled intersections in a neighbourhood or possibly from other sources (FCD data is very suitable) can be used for this task. In case that such a data is not available, it is advisable to deploy traffic detectors in a neighbourhood for a specific time period (at least 1 month) and to evaluate traffic burden.

B. From the perspective of NETWORK, the following is monitored:

- **Existing usage of sensor technologies/detectors.** It is desirable to analyze existing systems in a given location or its vicinity in order to arrange their cooperation. These are induction loops, strategic detectors, detectors at the intersections, camera system of a municipal police, parking meters etc.
- **Telecommunication coverage of given locations.** Considering the fact that telecommunication is absolutely fundamental component for sensor networks´ communication, it is necessary to analyze availability of the technologies in the area for which a system is planned (e.g. existing municipal wireless or optical network, national internet of things network, e.g. SIGFOX, LoRa, NB-IoT, coverage by mobile phone networks). Specific information on these networks is listed in the chapter 4.

- **Coverage by powering infrastructure.** Control unit with connected to the internet (router) needs to be powered, it is therefore desirable to monitor powering options in a given location (e.g. existing street lightning lamps with permanent/transient voltage and their bearing capacity and suitability). It is also advisable to consider the option of using photovoltaic energy sources (sunny, shady spot) depending on energetic requirements of specific system components.

- **Existing interference and shielding elements.** In order for a sensor technology to function efficiently, it is desirable to trap the interfering elements such as full-grown trees or tall buildings, rugged topography of a location, i.e. e.g. many interconnected twisting streets, enabled safety systems in buildings that cause telecommunication interference etc. For magnetic sensors, tram-line can present significant interference element, as presence of trams (especially setting in motion and braking) may affect accuracy of a measurement.

C. From the perspective of TRANSPORT INFRASTRUCTURE, the following is monitored:

- **Road surface**
  - **Asphalt paving.** Sensor technology can be placed underneath the road surface. Cold bituminous mixture can be used to skin the sensor.

Figure 1: detector Installed at the spot with asphalt surface

  - **Cobblestones.** It is possible to use sensors integrated into the **cobblestones** e.g. in historic city centre where the surface is made of these **cobblestones** and existing cultural – historical value of a place stays preserved.

Figure 2: Cobblestone with integrated detector (suitable for installation in historic districts)

- **Concrete pavement.** Again, cold bituminous mixture can be used or possibly joint sealing compound or respective cement mortar in order to achieve "grey" hue.

- **Number of lanes.** With higher number of lanes, i.e. 4 and more, non-intrusive technological solutions based on detection by means of a single device (i.e. camera, radar, lidar etc.) are preferred.

Figure 3: An example of a proper road marking.

- **Geographic segmentation of a parking lot in relation to parking sensor technologies.** Parking lot size and shape determines suitability of using camera system compared to deployment of detectors at parking places. Locations with no shielding elements (trees, tall buildings) with high concentration of parking places (e.g. shopping centres) are convenient to be detected by a camera system with the option of synergic use e.g. for detection of suspicious or criminal behaviour.

- **Missing road signs**. Both image recognition technologies and parking lot occupancy systems with individual sensors may experience difficulties with optimal distribution or with reliable detection of parking vehicles unless the parking places are defined by road marking.

D. From the perspective of SOCIAL IMPACT, the following is monitored:

- **Vandalism threat.** History of criminality and vandalism manifestations in a given location, i.e. realistic durability/resistance of a system as well as reliability of a system shall be considered in selection of a technology.

Figure 4: Parking meter damaged by a vandal (Slovakia)

- **Privacy** v. criminality. Distinguishing of the need to monitor vehicles core (i.e. distributor) roads because of e.g. possible occurrences of stolen vehicles and the need to monitor traffic burden in city streets; i.e. consider higher requirements for privacy protection and GDPR (it is more suitable to prefer anonymized detection technologies wherever possible). In this context, it is also necessary to consider acceptance of a technology by the public which perceives "anonymous" technologies much better than e.g. camera systems.

- From the environmental perspective, we monitor **impact of weather conditions and other influences** (e.g. trees complicates analysis of camera system recordings, infrared detectors are sensitive to fallen leaves, dust or snow).

E. From the perspective of investment and operating costs, the following is monitored:

- **Costs.** Besides acquisition price, the tenders shall also include operating costs, i.e. costs of data connectivity, necessary system maintenance and monitoring of system operation (monitoring of status events); nevertheless, it is also necessary to consider costs related to complexity of project documentation (building permit, intricacy of connecting to existing communication network, intricacy of installation in terms of both time and construction works, i.e. transport engineering measures implicating traffic restrictions). It is recommended to consider system costs related to its whole lifespan.

4.2 Setting the objective of introducing the smart parking tool in selected location

This step aims to define main objectives that an investor or more precisely a contracting authority wants to be achieved by deployment of a sensor technology in a given location. Predefined objective or set of several objectives enables selection of sensor technologies and specification of their deployment in an infrastructure. Location characteristics´ evaluation results also present an input into this selection. Selected sensor technologies then constitute subsystems of sensor network and enable connection to information and control systems. This enables direct real-time regulation based on detected conditions.

The objectives are as follows:

A. **Objective 1: Traffic Burden Monitoring (Traffic Burden Monitoring System, TBMS)**

Purpose: Specification of the metrics for monitoring of achieved objectives and setting-up of regulatory measures in a given location.

Description: In general terms, it is a system enabling traffic burden monitoring which is low-cost and definable as monitoring system of the internet of things (IoT). It is composed of two parts:

- Traffic flow monitoring
- Air quality monitoring

It enables area-wide detection of current and long-term traffic burden even in smaller streets.

When evaluating what shall be achieved, the following scenarios can be considered:

A.1 Scenario: **Sensor technology monitors amount of vehicles**

The system is able to count the vehicles that enter or exit a given location. Such system is based on traffic flow detectors (e.g. magnetometers) deployed in all city streets (of a given zone) that enable vehicle counting. They can also detect lengths and speeds of vehicles entering a zone which improves information for purposes of modelling of traffic impact on the air quality. Occupancy of street parking places in a location can be calculated by continuous data comparison (naturally presuming that the detectors are sufficiently accurate and reliable). Amount of vehicles in the streets can be then transferred to the model of noise and air quality for each street/smaller area within a zone and as such, it aids municipality in distinguishing places with urgent need of intervention by means of measures included in the Air Quality Action plan.

A.2 Scenario: Sensor technology monitors the air quality locally.

As the air quality modelling can become very inaccurate because of poor information on engine types and passing vehicles´ ages, monitoring system must be supported by **local air quality monitoring**. This is done by deployment of Air Quality ITS stations (AQ ITS-S) of respective class. Class C is acceptable minimum for TBMS (see below). The AQ ITS-S network has an advantage in its mobility which enables to change a measuring point from time to time and thus cover an area with air quality measurement sensors. Data from the AQ ITS-S network are used to improve the model (historic data analysis), to recognize other pollution sources (e.g. household heating, industry) and to provide precious data for evaluation of the air quality campaigns/measures´ effectiveness and gaining arguments for communication with the public.

A.3 Scenario: Sensor technology of digital image processing (of e.g. vehicle outlines, persons, license plates) of the vehicles entering a location.

Municipality can utilize existing camera network and provide similar data on traffic burden in the streets already covered by detection by means of image analysis. Besides criminality monitoring or video streams, existing camera system thus can provide also long-term statistics of mobility in a given street. Monitoring is not limited to vehicles, as pedestrians and cyclists can be counted as well. As it is necessary to always monitor whole area, it is advisable to complement existing deployment of this camera system network with both new cameras (especially at spots with heavy foot traffic) and the TBMS system.

Monitoring vehicles entering and exiting given location by means of a camera system featuring license plate reading is another alternative with higher operation costs. However, handling this private data is very problematic with regard to the GDPR directive.

A.4 Scenario: Sensor technology monitors observance of speed limits

The option of long-term anonymous speed monitoring is one of added values of the TBMS system. Continuous metering can reveal vehicles speed and length and thus also dangerousness of a given location with regard to traffic. Data can be then used for both selection of a lane and direction for effective police surveillance in the worst locations (see figure below, right lane in the direction of Čechův most) and adoption of traffic slow-down measures or implementation of the 30km/h zones. The system also enables backward evaluation and calculation of these measures´ impacts.

B. **Objective 2: Detection of parking capacities´ occupancy**

Purpose: Monitoring of parking place occupancy allows:

- To inform drivers about free/unoccupied parking places.
- To create accurate turnover/occupancy statistics of specific parking places and to keep statistics on drivers´ payment discipline.
- To navigate drivers to free parking places by means of guide signs or mobile applications.
- Availability of sufficient analyses for further development definition (parking policy, SUMP etc.).

Description: A system of parking place occupancy detection is used especially in places with high fluctuation where on-line information with an option to navigate to free parking places is offered to the drivers. Each parking place is monitored by a roadway sensor (magnetometer, IR detection, loop detectors) or detection takes place by means of cameras, radars or ultrasound that provide data on wider area occupancy.

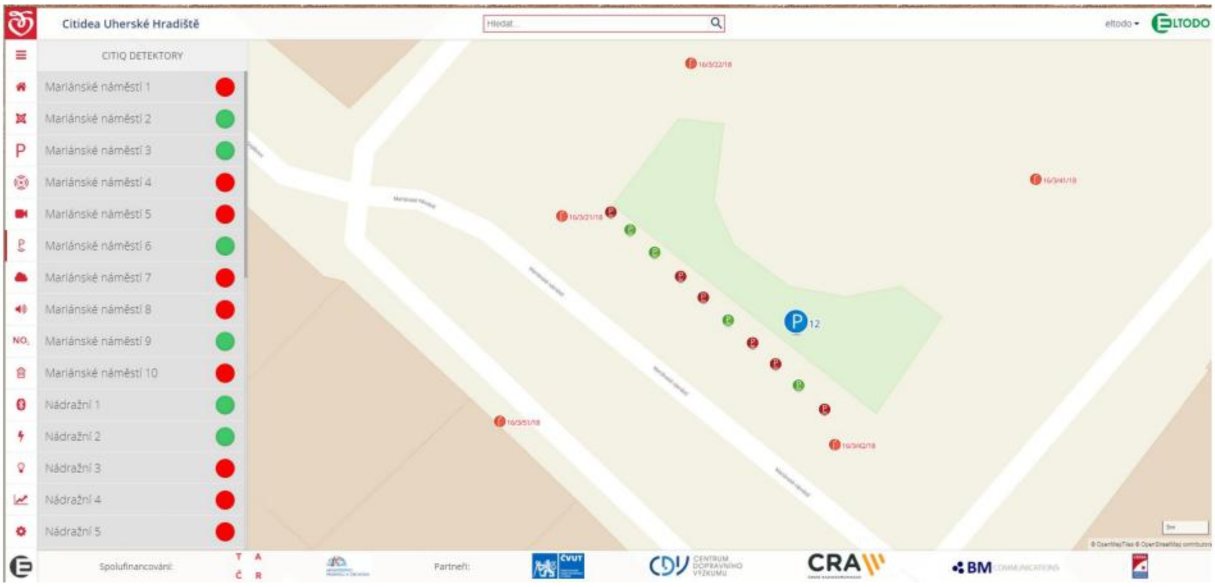


Figure 5: Schematic solution of parking lot detection by means of a camera system with payment discipline control

When evaluating what shall be achieved, the following scenarios can be considered:

B.1 Scenario: Real-time transfer of parking capacity information to the drivers by means of application or variable message signs

Sensor technologies detect occupancy of parking places (street parking, parking lots, P+R). The information is sent to a central server where occupancy of a spot is assessed or the assessment is done directly by a local system. Data from the server or local control unit is sent to a mobile phone/web application with a map layer or to variable message signs. Efficient provision of information on free parking capacities to the drivers enables reduction of wandering vehicles searching for parking places in a given location. If the information on free parking capacity is provided prior to entering a location, there is an option to offer drivers an alternative and not to navigate the vehicle into a location. While mobile application can also provide information on occupancy trend (e.g. perspective for the next 10 minutes), VMS can control traffic, i.e. deflect it during e.g. occurrence of congestion or significant levels of air pollution.

Figure 6: Traffic information device TID (product by the SPEL, a.s. company)

B.2 Scenario: Toll parking

Sensor technology detects parking demand and the relevant parking fees are gradually optimized in order to motivate the drivers to park their vehicles at parking facilities (off street parking) or in zones/locations that are not occupied that much. It is based on the effort to regulate parking so that standard occupancy level of street places is approximately 85 % which offers free parking places to the drivers who would otherwise wander around while searching for them. That way, the parking fees are adequate to actually measured demand. If the limit of 85 % is exceeded, the price goes slightly up while if the occupancy is lower, the price is reduced. The option to change the parking fee can be set for example for each three months. The system is also used **to modify charged parking period** according to actual demand on a specific location which allows for necessary flexibility of parking policy.

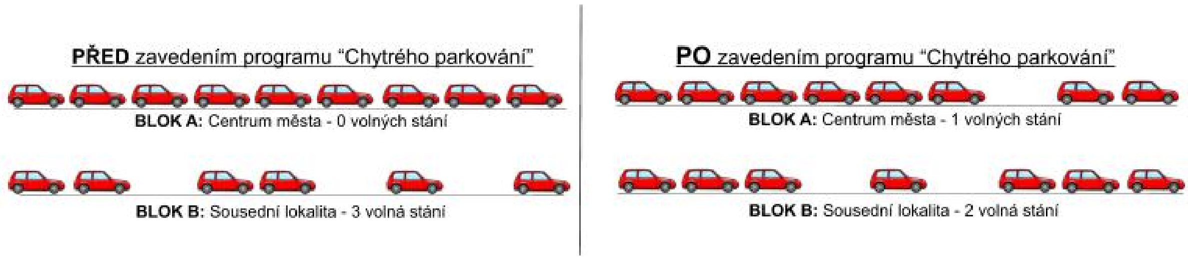


Figure 7: Example of impact of demand monitoring-based parking policy with very positive results demonstrated in San Francisco where the SF Park sensor system has been deployed on significant area of the city

C. Objective 3: Payment discipline and turnover control

Purpose: Sensor network enables long-term monitoring of individual places´ occupancy.

Description: When comparing with parking terminal data, it is possible to determine very quickly, almost in real-time, what are the payment disciplines at individual parking lots. To enable that, the payment terminals must be classified according to EN 12414 regarding data sharing at least as B1 to allow on-line communication with central server. For smart parking systems, the methodology recommends to deploy parking terminals of higher B2 class. This is the only way to ensure almost real-time monitoring and evaluation of data on issued tickets and possibly on executed transactions as well. It is advisable to combine the system also with personalized mobile phone application in which user sets up his license plate and police officer - besides visual check of the ticket – accesses the mobile phone application users´ database on inspection. There is also possible synergy in the form of application for navigation to free parking places and payment application. It is advisable for the parking mobile application's functions to include extension or reduction of parking time without arriving at the vehicle. The Smart parking system thus becomes complex, as it integrates all necessary components for stationary traffic regulation by means of technology and data.

D. Objective 4: Electronic system of residential parking and city logistics

Purpose: The system can distinguish parked vehicles of residents and handicapped or vehicles with special parking permit at specific places (e.g. delivery).

Description: This system is based on active recognition of a vehicle parked on a specific parking spot or in a dedicated location. The system comprises active infrastructure elements (where e.g. magnetic detector includes RFID chip) that enable communication with active/passive vehicle elements (e.g. resident parking card with a chip). At the central server, information on a parked vehicle (resident, handicapped etc.) can be assigned to specific parking spot by means of active card. This card is not transferable, always related to specific vehicle's license plate. In case that there is no parking card assigned to a vehicle, it is subject to obligation to pay for parking time by means of payment application or parking meter. The system can be also deployed with an active on-board device (Tag) which communicates with the network at a designated location (it is not paired with specific parking place). Location is equipped with the Master station which is e.g. installed only at residential parking locations or in Smart parking locations/zones.

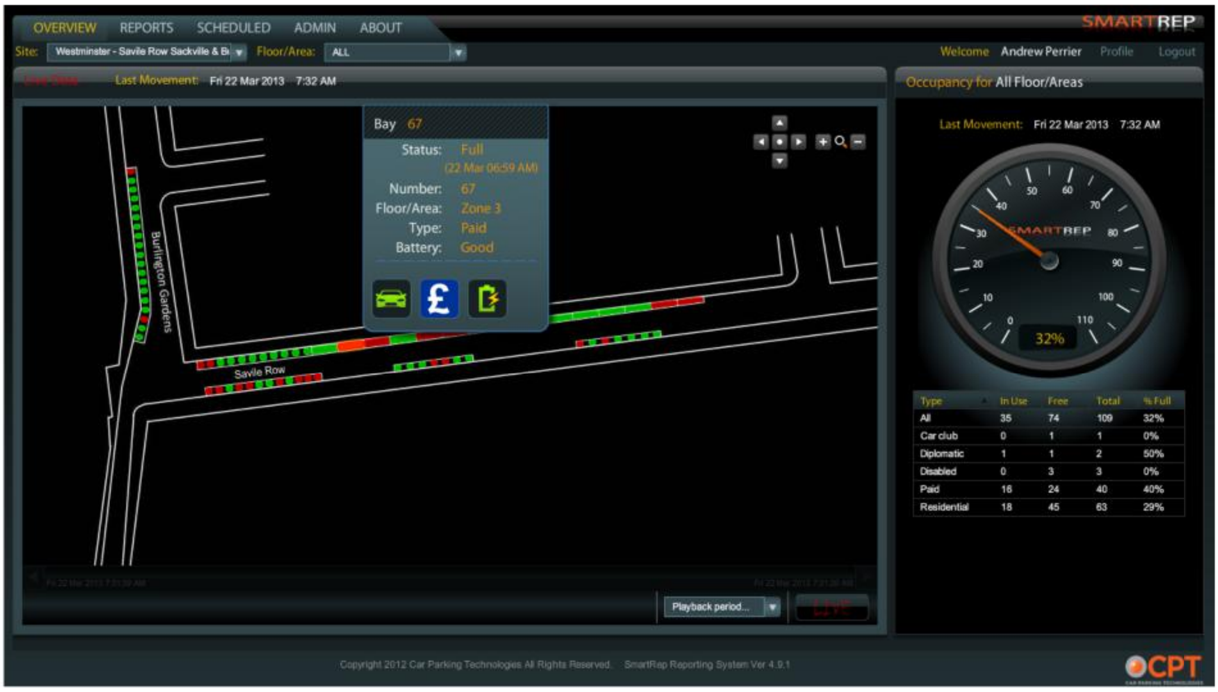


Figure 8: Glimpse into the system in Westminster where c. 3500 parking places are equipped with detectorswith RFID chips that communicate with specific vehicles equipped with parking cards with chips

D.1 Scenario: Deployment of electronic wallet

Direct communication between sensor and on-board identifier enables card holder to pay for parking in designated locations in a batch mode (e.g. 1x monthly) as vehicle is always registered by the system upon arrival to and departure from the equipped parking places. The system built in such a way is better in adjusting to flexible tariffs based on detected air quality or rush hours of specific days. Just like the above mentioned system (A)1, it can be deployed by means of communication network in zones/locations and active on-board devices that communicate with this network.

D.2 Scenario: Residential or prepaid parking place system

Holder of the active on-board element with prepaid amount for parking or after payment of the residential parking fee is entitled to use designated parking locations with no need of repeated payment at a location.

D.3 Scenario: System approach to city logistics

Given amount of parking places in inner city areas can be reserved for business entities and limited number of parking cards can be provided to them. The system can be set to allow parking only during designated days/hours. At the same time, it is possible to make a reservation for specific time of goods delivery and unloading.

Summary:

Continuous monitoring of the air pollution is processed for the locations where higher percentage has been detected during quantification of vehicles searching for parking places as higher air pollution is expected to be indicated here.

Sensor network composed of bigger amount of interconnected sensor technologies can eliminate or significantly improve actual conditions.

The methodology recommends composing the system of the following systems:

- **Traffic burden monitoring system** (TBMS) which is affordable and therefore suitable for traffic monitoring (zone solution)
- **Smart parking system** which is used for monitoring attractive parking lots and street parking with high turnover (location solution)
- **Payment and navigation system** which uses payment terminals and mobile phone and web applications to enable payment discipline control and to introduce toll parking system.

Appropriate localization of monitoring spots in a selected location will result in gaining sufficient amount of relevant data in order to propose sets of measures to improve the air pollution in general.

As deployment, operation and maintenance of the technologies present significant investment, it is necessary to considerable possible synergic uses for other purposes as well and **to build communication coverage prudently** and with involvement of all relevant city departments and public utilities. Interconnection of energetic, telecommunication or traffic purposes with waste collection, street lightning etc. within single communication network can result in a citywide communication standard for sensors and sensor network from various suppliers and for various purposes.

4.3 The proces for quantifycations of the car looking for a parking space

Current approach to traffic control focuses primarily to vehicles driving from point A to point B. Control logic is then adapted to this fact. However, interaction of moving and stationary traffic brings along hardly predictable impact of the traffic heading "nowhere", only to unknown parking place, which causes traffic flow to be badly predictable pattern of vehicles mutually affecting one another. Presently we are unable to assess how serious the problem is and what is its real impact on the environment in the Czech Republic. In this respect, specific methods enabling analysis and quantification of external damage caused by vehicles searching for parking places in specific zones/areas are described below. This data can be subsequently compared to data after deployment of (ideally blanket) smart parking system. At the same time, it can be basis for key performance indicator (KPI) formulation.

4.3.1 General principles

Quantification of vehicles searching for parking places is crucial in assessing which parking regulation to set up in a selected location and which sensor technology to choose.

Reasons for quantification of vehicles searching for parking places are:

- Specification of the metrics for monitoring of achieved objectives within applied regulatory measures
- Specification of target values of the monitored parameters (demonstration of change after implementation of parking regulation)
- Decision support groundwork for blanket detection[3]
- Decision support groundwork for paid parking extension

The monitored parameters are:

- Percentage of vehicles searching for parking places
- Determination of actual time amount spent on searching for a parking place
- Emissions/Air pollution
- Noise

3 {Basic system is used for deployment of technologies detecting vehicle presence at selected parking places which enables online monitoring (occupancy of specific parking place, percentage occupancy rate of a parking lot etc.)<0}

In order to gain relevant data, the quantification shall adhere to several rules mentioned below.

Chapter 5 deals with quantification of emissions and noise in a greater detail.

Below mentioned principle of quantification of vehicles searching for parking places has been pilot-tested and verified in the vicinity of the Roosevelt Street in Brno, Czech Republic.

4.3.2 Quantification preparation - project

Quantification of vehicles searching for parking places in a given location is carried out within a timeframe according to predefined schedule specified in a project. The project is elaborated for a whole location, taking into account situations in its individual streets.

The project must contain the following parts:

A. **Monitoring point localization**

Results of expert prediction and familiarity with a location are considered when designing monitoring points and sensor technologies deployment.

The following items have to be prepared:

- Evaluation of collector and distributor roads through which vehicles enter/exit a location
- Base map of appropriate scale with accurate identification of the monitoring points in a given location including their GPS coordinates

Both number and exact placement of the monitoring points depend on specific situation of a road or a given lay-by. It is advisable to define these places accurately, especially because of preparation of the deployment itself and enabling repeatability of quantification if needed. This need can result for example from construction of a new parking house.

Procedure of quantification points´ placement in a given location is advisable to be consulted with quantification commissioner and authorized municipality representatives in advance. If a monitoring point shall be placed on a private land or infrastructure (lamppost, traffic sign supporting structure etc.), owner's approval is to be obtained.

B. **Project design must consider requirements of commissioner or authorized bodies regarding especially the following items:**

- Specification of data collection frequency
- Data evaluation and archiving system

C. Project must take into account also possible drafts of closures related to sensor technology installation.

D. **Project must comprise technical documentation related to sensor technology installation:**

- Geodetic documentation

4.3.3 Sensor technologies for quantification

Selection of sensor technology for quantification must be based on:

- Analysis of existing sensor technologies/detectors deployed in a given location
- Possibility of using portable high-resolution cameras with the option of back-office post-processing
- Telecommunication coverage of a given location
- Coverage by powering infrastructure
- Existing interference and shielding elements
- Funds allocated for the quantification

4.3.3.1 Alternative 1: Survey carried out by means of the ANPR technology in a central area

Description: General principle of this approach is deployment of necessary amount of cameras with the options of image recording and vehicle license plate assessment. This can be done in two ways:

1) Cameras with digital image processing at the deployment spots with remote data transfer
2) Cameras recording the image which is subsequently loaded into special SW to assess vehicle license plates

The first alternative presents higher costs of recordings and higher demands on the approval process (necessity of installation on existing infrastructure). On the other hand, the survey can be carried out in a longer term.

The second alternative implies rather short-term metering (days) while individual camera points shall be attended manually.

For metering and subsequent assessment, required amount (based on the project) of high-definition recording devices is used in order to detect license plates of passing vehicles at predefined spots.

Placement of individual cameras shall correspond with possible vehicle routes in a monitored area to compile matrix of transport relations in a wider area.

Survey structure:

- Placement of cameras based on the elaborated project
- Elaboration of technical documentation (connection of cameras to the street lighting network)

Figure 9:Example of portable camera points´ deployment while carrying out a survey in the vicinity of the Roosevelt street in Brno

Assessment by ANPR:

	Wandering vehicles searching for parking places	**Passing vehicles**
Route description	• Vehicles that entered a zone, turned around	• Vehicles that enter a zone in any direction and

	and changed travel direction within it (or possibly left it again = did not locate free parking places) • Vehicles that entered a zone, turned around and changed travel direction within it and then entered garage by the Janáček theatre (did not locate free parking places and entered the garage)	that leave it without turning around within • Vehicles that were already present in a zone and left it (already parked vehicles that left the zone)

Table 1:Simplified description of recorded image assessment at specific location in Brno

4.3.3.2 *Alternative 2: Survey carried out by means of questionnaire*

Description:

Questionnaire surveys are used either to complement camera system survey or as stand-alone solution where using cameras is not an option (because of economic or other reasons). In general, it can be said that questionnaire surveys can collect sufficient amount of information to substitute data gained in directional surveys by means of camera systems. However, it is necessary to address sufficient amount of respondents. Camera surveys can calibrate or efficiently expand the survey results.

Survey structure:

The questionnaire surveys are conducted in “face to face“ manner which includes approaching drivers of cars parked in a given location. The drivers are asked questions and the assessment is made according to their responses.

The questions are following:

1. Reason for occurrence in an area.

2. How often do you drive to this area?

3. How long did it take until you found a parking place in this area?

4. Assessment of traffic flow on the way to the area.

5. Assessment of simplicity/complexity of search for a free parking place.

6. Are you resident?

7. How old are you?

8. Gender.

9. Number of persons in a vehicle.

10. Would you use an application for navigation to free parking places?

Assessment of the questionnaire survey:

It is advisable to carry out the survey before introduction of a parking regulation as groundwork for determining of a situation before implementation and subsequently to carry out the same questionnaire survey after implementation of measures.

Implementation of detection technologies in parking areas belongs among so-called public benefit projects. These projects aim to increase benefits of all subjects, i.e. to be useful for citizens. Implementation shall bring positive impact. The questionnaire survey can be thus complemented with questions related to quality indicators of specific measures.

This means that in case the parking regulation comprises for example detection of free parking places and their progressive pricing, the questionnaire will include a question of the sorts e.g.:

Are you satisfied with set tariff pricing?

4.3.3.3 Project benefits´ characteristics

At the end of the analytic part, we list basic implementation benefits of the Smart parking system, mutually compatible with the air quality monitoring system. These benefits shall make part of elaborated Feasibility study which shall precede design and implementation of a system. The most significant benefits of such a system implementation comprise:

A. **System user benefits**

By implementation of a system, clear rules become valid for the users; in case of parking lot operation by a private subject, they are valid also for public operators. Municipality keeps track of how the whole parking system operates, what amount of funds it generates, what locations are still the most attractive, at what times and on what occasions, however, its fundamental benefit is its interconnection with other city agendas. For example, interconnection with public transport or city bike system (bike sharing) can be carried out by a single payment instrument (payment card, mobile phone application) and users can thus collect positive points in exchange for environmentally friendlier behaviour. Smart parking system with flexible tariffs and interconnection to the air quality monitoring system has a potential for significant impact on amount of vehicles in city centres: partly by positive media campaign and partly also by available information on parking lot occupancy and on flexible tariff rates that are dynamically modified based on pollution values. The system can contribute to increased quality of life in city centres.

B. **Economic benefits**

Parking systems belong to a few intelligent transport systems that can create direct profit for city treasury. From the perspective of the Smart city concept, these monetary resources (or certain part of monetary resources) shall be allocated into pre-designated fund (e.g. mobility fund, ITS development fund etc.). Specification of the system management rules is one of the preconditions for positive economic balance of the system implementation. Municipal corporation can operate and maintain the system on its own (total control over revenues, transparency etc.) or it can use the system supplier also for operation and maintenance of the Smart parking system. The supplier can be motivated by flexible reward/sanction amounts for accuracy and reliability of the system. Economic benefit aspects comprise especially:

- **Increased payment discipline.** The experiences abroad show that it is reasonable to expect the payment discipline to almost double provided that the supervision is effective. The Smart parking system provides supervision bodies with accurate and localized data related to payment discipline infringements. The detection systems can be also deployed at the waiting/stopping prohibited spots. If a violation of rules occurs, police patrol can take effective and fast action as well.

- **Flexible tariff rates** can bring more funds into the public budget.

C. Environmental benefits

- **Motor fuel saving.** Based on findings of traffic surveys before and after measure implementation, it is quantified what amount of fuel is saved by reducing the distance traveled by an average vehicle during search for a free parking place. The saving is converted into monetary resources by means of average fuel prices.

- **Reduction of greenhouse gas emissions.** Average amount of km travelled before and after putting efficient parking system into operation will be also reflected in emissions of greenhouse gases, especially carbon dioxide (CO2). If percentage of vehicles searching for parking places is reduced and the information on free parking capacities are distributed through various media, the emissions of greenhouse gases become affected. Significant reduction of greenhouse gas emissions can be achieved in the periods of poor air quality when increased parking tariff scenarios can be triggered. The system designed in such a way can significantly reduce amount of vehicles heading to central area of a municipality. As a countermeasure, ecological public transport can be supported.
- **Reduction of noise pollution.** When percentage of vehicles unable to locate free parking place is reduced, impact of these vehicles on traffic flow on the roads surrounding locations with high parking place occupancy is reduced significantly. Increased traffic fluency also results in lowered noise pollution in these places.

D. **Time saving**

Time saved during search for a parking place with mobile phone application or other elements of the Smart parking system is converted to financial units by means of data onConclusion of analytical part

5 Data management system part 1: Implementation and integration into information and parking control systems

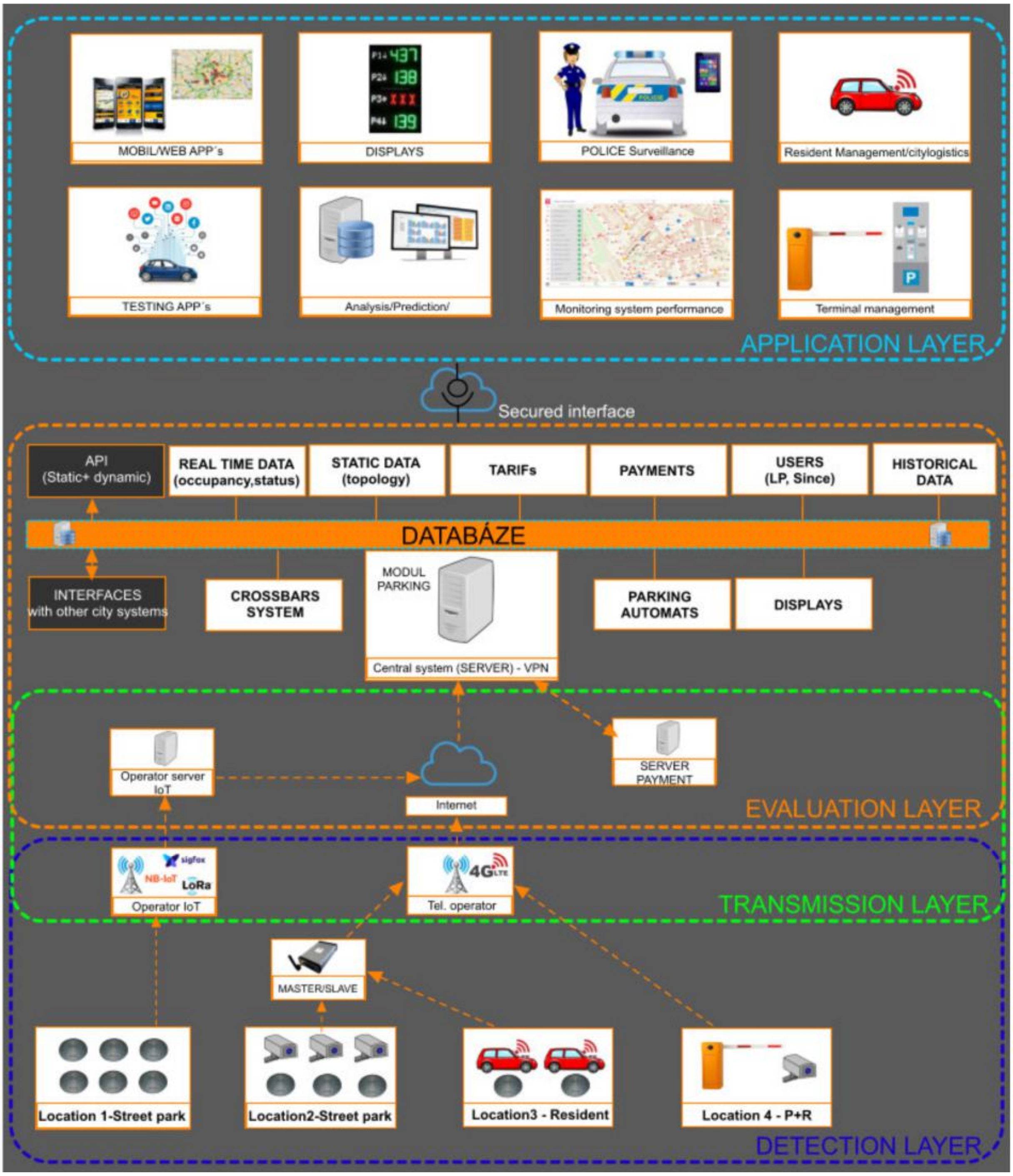
5.1 Generaly

In generaly parking strategy needs to be solved as a complex system in several consecutive steps as to maximize the benefit from the newly installed or existing systems. The smart parking system is also part of the Smart Cities concept that is based on data driven decision making where data can be generated by various detection systems providing information to central processing, for example in the traffic information centers. After processing the data, the information is stored in the database and is used by the application layer or is subsequently used for analytical tasks. For the purposes of this document the **ICT tool _Smart Parking Regulation scheme** is divided into the following layers:

- ✓ Detection layer
- ✓ Transmission / communication layer
- ✓ Evaluation layer
- ✓ Application layer

In particular, this regulation parking scheme focuses on smart technology that can be used to effectively address street parking in connection with Low emmission zone and other forms of urban access restriction. Also regulation scheme can be in connection with other form of parking (parking spaces, parking areas with barrier systems, etc.). This **ICT tool _ smart parking** also has side benefits, for example, for transport and land-use planning and valuable information for suistainable urban mobility planning.

The scheme below present basic architecture of parking regulation scheme



Scheme 2: The parking regulation scheme architecture design

5.1 Detection layer

The detection layer is composed of sensors, which allow recording the moving, resp. standing vehicles at specific parking spaces. There are various sensors available on the market based on different physical principles. Sensors have their advantages and disadvantages, so they need to get acquainted with their primary uses. The choice of the appropriate technology depends on the needs of the end-user, the results of the analysis and the set of conditions for the individual sites considered (see above).

More detail about technology can be found in SOLEZ DT2.1.1.

5.1.1 Traffic flow monitoring cameras and / or cameras with vehicle reading function (ANPR)

An efficient and stable Traffic Flow Tracking and Traffic Control and Automated Vehicle Plate Reading (ANPR) surveillance system is particularly suited to control entry into the specified zone. It requires permanent power supply and has high demands on data transmission (fiber optics). Reliability of cameras for license plate reading is determined by the location in which they are installed. In particular, the lower the speed of the sensed vehicles is, the higher the reliability of detected license plate is provided. It is necessary to consider higher investment costs and high maintenance costs (regular cleaning of camera lenses due to dust, spider webs, etc.). If the system is deployed in the streets, it is exposed to vandalism. Also, weather conditions and night traffic have a significant impact on reading reliability. Deployment procedures are relatively complex and require a considerable amount of time and permission (paper work). It is also the subject of GDPR and Privacy Protection measures, and in most countries it requires the police to be the sole supervisor.

5.1.2 Traffic loop for traffic flow monitoring

An efficient and stable traffic flow monitoring and traffic management system serves as a strategic detector. It can be used as a technology for counting the entrances / exits from a given parking space. Requires continuous power, has higher acquisition costs and maintenance costs. Deployment procedures are less complex and require less time than cameras. Installation is not fast and easy. It is often associated with traffic lights control (the controller acts as a system control unit) and as such is much more expensive for cases like access control to parking spaces. It has no other purpose.

5.1.3 Magnetometers for traffic flow monitoring

An effective and new type of traffic monitoring system, especially for surface traffic monitoring (air quality system) that is not yet widely used. It can also be used as a technology for counting entrances / exits from a given parking area. It is an energy-independent system, which means very easy and quick installation, but it is a matter of time when the battery of the detectors is discharged, so it is important to consider the ease of replacing them (removing it from the road). It is an inexpensive system with low maintenance costs. It is an IoT system that allows the integration of other traffic monitoring sensors in neighboring areas (it can also monitor traffic on adjacent roads around the facility). It can be combined with parking sensors and track only specific locations (based on user type, e.g. handicapped). For the purpose of this document, this system is called the Traffic Burden Monitoring System (TBMS).

5.1.4 Cameras for monitoring the occupancy of parking spaces

An efficient and continually improved parking tracking system where parking spaces are accumulated within a given area so that the given area shape is effective as they can use their potential (i.e. up to 100 parking spaces with a single camera). Image analysis allows you to track the occupancy of a car park and cover a large area with several cameras with acceptable levels of accuracy. Cameras can be set up as simple sensors where the image is processed and evaluated by the camera itself, and the data output is only a numerical expression of the occupancy of the parking lots. This type of camera utilization is very good because it means low data transmission costs and there is no need to address any major issues with GDPR. Adverse weather conditions may, however, have a significant effect on the reliability of the output. Acquisition cost is lower than occupancy detectors. However, higher maintenance and servicing costs (cleaning lenses, etc.) have to be taken into account. The camera system may also be subject to vandalism and / or malfunction, which in case of failure of one camera will cause the entire monitored area to fail; this is rather a disadvantage compared to an occupancy detector based system where sensor failure means a failure in the order of one parking space. In the area of street parking it is suitable in combination with magnetic or IR sensors, as vehicle overlays, trees, or other infrastructure elements can influence measurement accuracy. Cameras cannot be used in all locations considered. Digital image processing cameras can have a synergy effect for asset protection, pedestrian and cyclist counting, and other image recognition outputs, video streams for road reconstruction, or any other activity in the monitored area.

Figure 10: Camera based system illustration (source Designa, s.r.o.)

5.1.5 Parking space occupancy detectors (magnetic and IR sensors)

These are an efficient and new type of parking tracking in areas where parking spaces are subject to high demand. It is energy-independent, which means very easy and fast installation in place, but not on a larger area. The batteries are discharged for a much longer time (about 5-10 years) than with a highly loaded traffic flow detector, so it is not as important to consider the ease of replacing them (removing the road). This is a system with slightly higher acquisition costs compared to the occupancy camera system (this depends on the number of places where the camera has a meaning to consider if the system covers more than 20 lots), but with lower maintenance costs. It is an IoT system that allows the integration of other sensors e.g. to monitor traffic in neighboring areas (except for parking the system can also be used for transit detectors control on adjacent roads within reach of the device), only specific locations (type of users, e.g. handicapped) integrate detectors of other phenomena (communication network for energy and water netmetering, waste management, etc.)

It is also possible to use a centralized IoT solution (SIGFOX, LoRa) where separate detectors are purchased without a local control unit, but such a solution involves higher data transmission costs and also a limitation of the frequency of data transmission per hour / day (conditions of the national telecom regulator). Based on the CDV survey, it was found that attractive high-turnover parking lots (short-term parking, higher number of parking vehicles per day) are better implemented via local IoT networks with a high frequency of data exchange and the SIGFOX solution is insufficient for these locations as the maximum number of messages per day is 144 from one end device.

Figure 11: Magnetometers illustration; road embedded sensor (left) and surface sensor (right), source: CITIQ, s.r.o.)

Figure 12: Magnetometer illustration; integration into a pavement cobble (Source: CDV, v. v. i and CITIQ, s.r.o.)

5.1.6 Barrier systems

An efficient and stable entry control system that is suitable for parking lots with more than one location and ideally with one access road. They need a special space for about 3 vehicles in a row so that vehicles standing in front of the barrier do not affect traffic on the main road. Barrier systems represent a barrier to traffic flow, which is not a supportive solution for smart cities, as the concept itself defines itself against barriers. The barrier system is not suitable for important places in the city. It is common that the system does not have good reliability for accurate vehicle counting but is ideal for regulating the entrance. The purchase price is relatively high, maintenance may be costly, as it sometimes requires special intervention by the operator because the barrier can be subject to a fault and becomes a real barrier, for example, for the driver leaving the car park. The barrier system is often associated with a camera system or ticket dispenser, so the system is complex. The system is designed for one purpose only.

5.1.7 Radars

An efficient and stable traffic flow monitoring system, particularly suitable for multi-lane roads that can also classify vehicles and determine their speed in addition to simple traffic counts. Its measurement is not entirely reliable in the case of standing vehicles, therefore this technology is suitable for motorways, highway and national roads, or trunk roads in cities where traffic flow is continuous. It requires continuous power and has higher acquisition costs. Data transfer demands are not significant. It is also used to monitor the occupancy of parking spaces for on street parking, but the cost of such a system is significant, exceeding all of the above systems. The system is designed for one purpose only.

5.1.8 RFID

Appropriate supplementary system for smart parking, especially for residential areas. The system is built on communication with passive tags (RFID transponders).

The owner of these tags may be a resident, subscriber, or person with reduced ability to navigate or move. RFID antennas can be installed either at the entrance and exit to designated locations (similar to ANPR cameras), or they can be installed directly in the surface mounted detectors (magnetometers/IR detectors). Such a system is very investment-intensive, and the operation of such a system is not negligible (need to replace the batteries in the roadside sensors as the RFID readings require higher energy demands). The system can be synergic e.g. for city logistics systems, city cards systems etc.

Figure 13: Infrared parking detector with integrated RFID (Westminster case)

5.1.9 Decision making survey on suitable technologies for various purposes

Technology	City strategy	Locality importance	Locality geography	Technical complexity	Operation complexity	Synergy with Smart City concept	Cost
TBMS	Suitable	Suitable	Suitable	Low	Low	Suitable	Low
Magnetic/IR sensors	Neutral	Suitable	Suitable	Low	Low	Suitable	Medium
Cameras (detection)	Neutral	Suitable	Neutral	Medium	High	Suitable	Medium
Barrier systems	Unsuitable	Unsuitable	Suitable	Low	Low	Unsuitable	High
Inductive loops	Suitable	Suitable	Suitable	Medium	High	Unsuitable	High
Microwave radar – (parking)	Unsuitable	Suitable	Suitable	High	Low	Unsuitable	High
ANPR cameras	Suitable	Suitable	Suitable	High	High	Neutral, rather non suitable	High

RFID	Suitable	Suitable	Suitable	High	High	Suitable	High

Table 2: Comparison of detection technologies for Smart parking system decision making

Technology	On street parking	Parking houses	P+R	Open areas (more entrances/exits)	Residential parking	Notes
TBMS	Suitable (with a limit)	Suitable (in combination)	Suitable (in combinatio n with barriers)	Suitable	Unsuitable	Traffic flow detection without occupancy information
Magnetic/I R sensors	Suitable	Suitable	Suitable (higher investment)	Suitable	Only in combinatio n	It measures parking occupancy
Cameras (detection)	Suitable	Unsuitable	Suitable (higher investment)	Suitable	Unsuitable	Accuracy is limited by trees, shading and/or weather conditions
Barrier systems	Unsuitable	Suitable	Suitable	Unsuitable	Unsuitable (only for dedicated places)	Affordable but serves for one purpose only
Inductive loops	Unsuitable	Suitable (in combination with barriers)	Suitable (in combinatio n with barriers)	Unsuitable	Unsuitable	Suitable for one entrance/exi t without occupancy information
Microwave radar - (parking)	Unsuitable (high cost)	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Suitable for traffic flow monitoring on trunk roads
ANPR cameras	Applicable	Suitable	Suitable	Unsuitable	Applicable	Problem with public acceptancy, technology limitations
RFID	Applicable	Applicable	Unsuitable	Unsuitable	Suitable in	In the future

	(without parking occupancy)	(clients)			combinatio n with magnetic/I R	it is expected its wide deployment in smart parking

Table 3: Applicability of technologies for various parking areas types

5.1.10 Evaluation of the detection layer

For Smart On Street Parking and with regard to the gradual development of the citywide system, it is recommended to use the following technologies:

- Magnetic, infrared sensors that are installed on each particular parking space
- Camera systems monitoring the occupancy of parking spaces

It is recommended to use a combination of these two technologies to install a full-area system. This will ensure maximum synergy of technology and the highest possible investment efficiency. For specific zones / locations and the suitability of specific technologies, or a possible combination, a thorough site survey is required.

For the residential parking system, it is necessary to keep track of current technological developments. However, it is recommended to use RFID technology associated with resident cards and a synergy effect on city cards and payment methods in public transport.

5.2 Communication layer

The Wireless Internet of Things is a new technology for data collection. Each of these networks allows low data volume to be transmitted, but with very little power consumption. Therefore, it is possible to use communication modems also in devices that are powered by small batteries or solar energy, while maintaining a relatively long life (5-10 years).

The network consists of three basic parts:

- Nodes
- Gateways
- Server (backend)

Ad A. The nodes (communication and detection units) are small units equipped with a communication unit, microprocessor, memory, battery, and interface for connecting sensors. Nodes are already equipped with a large number of interfaces to connect multiple sensors (noise meter, thermometer, etc.). Some nodes collect data from multiple connected nodes and forward them to the gateway when creating local networks. These nodes are referred to as routing nodes (routers, repeaters, or very often referred to as SLAVE units).

Ad B. Gateway - Nodes collect and send data to the second part of the wireless sensor network that is the gateway (gateway, which is a unit with Internet connectivity). The flow diagram of the data flow between nodes to the gate is defined by the topology of the wireless sensor network. In the gate, the information is temporarily stored, ready for further processing, or sent for example through Ethernet communication (in the case of remote IoTs) or GPRS / 3G / 4G / LTE (for local IoT networks). They are often referred to as MASTER units.

Figure 14: Gateway (MASTER station, source CITIQ, s.r.o.)

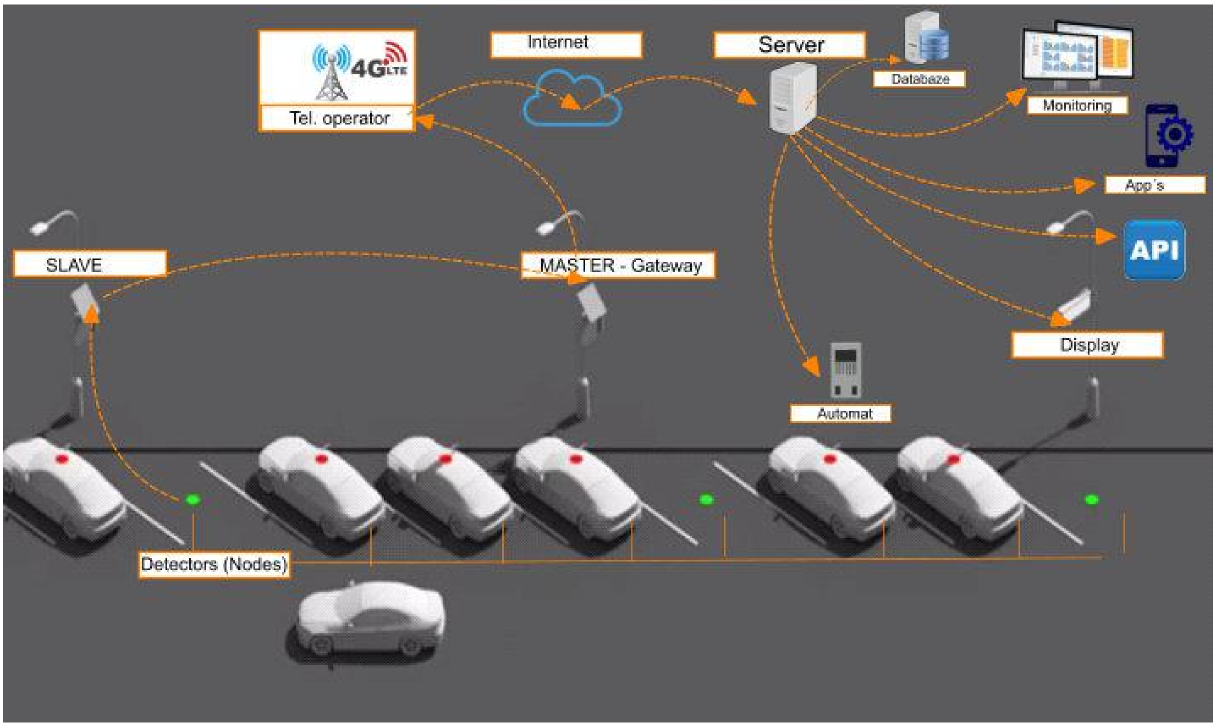
Ad C. Server - Data collected from the gateway is sent to the server where it is permanently stored. The server then conveys the data to the owners of the nodes for free use.

The Internet of Things Network (IoT) is further differentiated into:

- Local networks
- Remote networks

5.2.1 Local networks

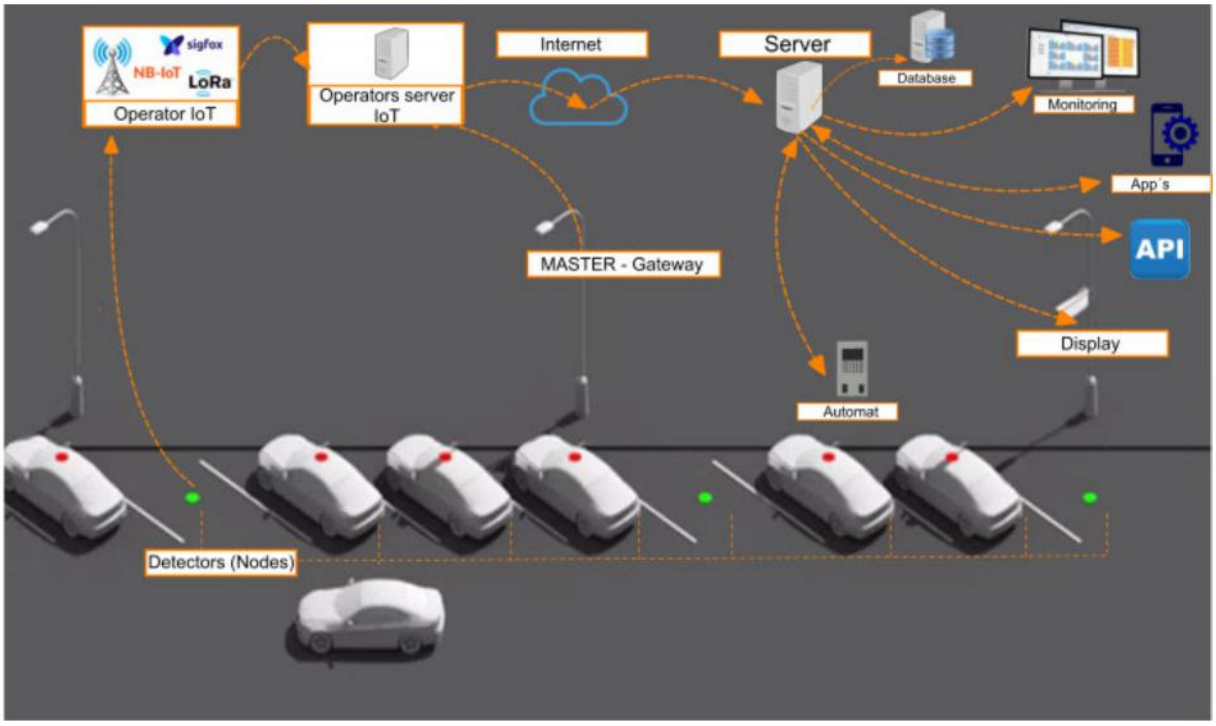
Local networks are made up of Nodes that send data to the Gateway for a short distance (up to about 1 km). In the case of long-range transmissions, so-called Repeaters (SLAVEs) are used to communicate to the Gateway, which convey data to the Gateway from more distant areas. Such network topology is called MASH networks. These networks are characterized by higher acquisition costs, but operating costs are consequently very low. The advantage of such a topology is also the possibility of the city building its own private IoT network and gradually connecting other nodes with different types of detectors (noise meters, traffic detectors, air quality detectors, etc.). The advantage is also that these network types do not have limitations in the number of messages sent from end nodes, as is the case for remote IoT networks (SIGFOX, LORA). Another advantage is robustness, better responsiveness to changes and better range than star variants. The Star Topology uses Direct Node Communications with the Gateway without Repeaters (SLAVE). From the Gateway, data is sent to the user's Server via mobile network (3G, GPRS, 4G / LTE). Of course the possibility of using Ethernet connections is also possible if such a network is available. The main representatives of local networks are IQRF or 6LoWPAN.



Scheme 2: Smart parking scheme – local IoT

5.2.2 Remote Networks

In the case of remote IoT networks there is no need to send data from Nodes to locally installed gateways, but data can be sent over long distances (up to tens of kilometers). Gateways are very often deployed at the base stations (BTS) of mobile operators. Compared to Local IoT networks, the cost to the network is very low, but it is necessary to calculate the annual fee for the communication operation of each single node. All devices in remote IoT networks must also be certified by the IoT operator for a fee. These costs need to be taken into account in pricing and system planning. Another possible limitation is the maximum number of messages sent from one Node.



Scheme 3: Smart parking scheme – Remote IoT

5.2.2.1 Sigfox

The network is often being built in cooperation with mobile operator or digital broadcasting operator (e.g. in the Czech Republic with T-Mobile), which provides its infrastructure for the deployment of base stations.

Sigfox is a technology that enables IoT devices to interact cheaply over long distances and safely at the minimum energy requirements required to operate. Typical areas of hundreds of apps in the Sigfox network are mainly netmetering of electricity, gas, water, parking detectors, Smart City, Industry 4.0, temperature sensing in logistics, storage, security devices, flood flow measurements in floodplains etc.

For large network reach, Sigfox uses the Ultra Narrow Band (UNB) technique; on the physical layer LPWAN is adapted through a variety of techniques for greater reach. Sigfox is therefore a narrowband technology. When used, it gives the ability to dimension the antenna as needed. Unlike IQRF, this network uses topology as a star, not mixed (MASH).

Just like the IQRF network, Sigfox works in a free license zone. This has certain disadvantages; however, the lower cost is very advantageous. For Europe, this is the frequency of 868 MHz, the band for the US is at 915 MHz. The fact that a band is free of license does not mean that it cannot be subject to certain local regulations.

Each Sigfox device is limited by the number of messages sent, namely 144 messages per day, which is an average of 6 messages per hour. The return direction is limited to 4 messages per day.

With the SIGFOX network, devices, things, and sensors can be independent of cabling power because the battery can last for 5 to 15 years and can communicate reliably while maintaining security while the cost of communications and modems is in the order of single Euros per month / node. This facilitates the abundant deployment of millions of devices.

A simple programming interface allows building applications above data or integrating them into enterprise systems in the order of hours or days.

5.2.2.2 LoRa

Long Range is the meaning of LoRa. For example, we can see LoRaWAN. It is created by the name LoRa and LPWAN, which is WAN wireless technology. LoRa is created by the association named LoRa Alliance, which focuses primarily on M2M, the Internet of Things, smart cities.

Unlike Sigfox, which uses the UNB technique on the physical layer of LPWAN, LoRa uses the direct sequence spread spectrum (DSSS), which means spreading spread spectrum. Lora is broadband, allowing it to communicate at low power levels. It uses a modulation that changes carrier frequency, called FSK (Frequency Shift Keying).

LoRa can reach 15-20 km and the low-energy device lifetime is for about 10 years. Thanks to the LoRa broadband, it resists noise. Operation is provided both unidirectionally and bidirectionally. Adaptive Data Rate (ADR) is a device that adjusts data flows according to the actual needs and conditions of the device. This increases the battery lifetime of the end device and network capacity. The end devices are divided into 3 classes (A, B and C) differing in capabilities and price.

5.2.2.3 Summary for deciding on the suitability of communication

Network type	Suitability for sensors network	Range	Purchase cost of sensors network	Operation cost of sensors network	Data limit ona single connected device	Notes
LORA	High	Medium	Low	Higher	According to the class and contract	Interference with buildings and barriers. Sometimes the network should be densified.
SIGFOX	High	High	Low	Higher	144 messages / node	Stable connection
Local networks (IQRF, 6LOwPAN)	High	Low (local networks)	High	Low	According to 868 MHz	Suitable for city networks. Building of own IoT
NB IoT	High	High	Low	Higher	/	Not tested
3G/4G/LTE	Low	High	High	High	According to the contract	Not suitable for IoT

Table 4: Survey of basic capabilities of IoT networks

5.3 Evaluation layer – Central system

For operators working on a specific issue, it is necessary to monitor the matter in much more detail in addition to a general overview. Below is an example of an integrated visualization tool over parking policy that allows administrators to track statistics on the type and timing of parking, occupancy, payments, or users within a single map. Without such tools, it is difficult to achieve effective parking regulation and adequate pricing policy.

Figure 15: Integration platform of Smart Parking system including connected data from other sources (This is a SW result of the Czech R&D project Smartnet). SW provides visualization of parking data from various sources, i.e. sensors networks, payment terminals and shows the actual status of all the connected devices)

The central system is depicted in the system architecture as a Server on which all the computational operations take place. The "Smart Parking" Central System should act as a separate plug-in module for the city's or county's traffic and information management system.

The central system (server) aggregates data on occupancy of individual parking spaces. The user interface and the administrator interface are part of the central element and through these interfaces the system is set up, parameterized, and can be adjusted for individual parking zone tariffs. It is recommended that local elements can be controlled and upgraded from the central element on the infrastructure. The central system controls all peripheral devices (parking vans, detectors, displays, etc.). When building a system, it is necessary to remember the creation of an open interface (API), to which third-party entities can access and create their own solutions and applications. The interface is required to be created in the standard format according to CEN TS 16157-6 DATEX II.

5.3.1 Central System input data

The Central System works with:

- Static data
- Dynamic data

5.3.1.1 *Static data*

Ensuring proper operation with the subsequent provision of required services must be based on fixed, static data that should be editable at the administration level. For the correct functionality of the system, at least the following static data are required:

- Zone Identification
- Identification of Tariff Zones
- Identification of the parking area (e.g. *Revolution Street*)
- Identification of entry and exit to the area
- Identification of the parking block
- Identification of the parking space
- Identification of the type of parking space (e.g. disabled, longitudinal / transverse / perpendicular, etc.)
- Identification of the sensor
- Location of the parking slot

These static data should be provided through an open interface in DATEX II format that ensures interoperability with third party systems (e.g. navigation providers, end-user mobile applications, etc.).

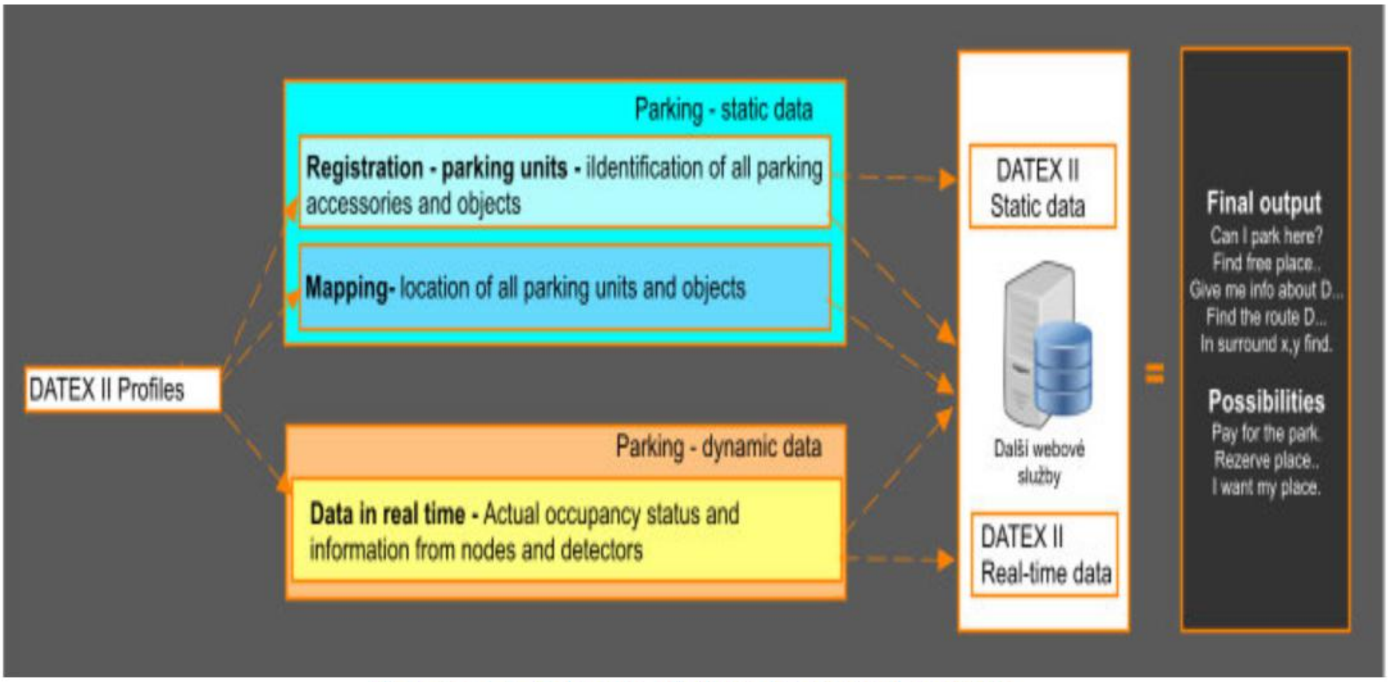
5.3.1.2 *Dynamic data*

Data transmitted from each Node on the transport infrastructure to the Central System (Server) must be as follows in the minimum format:

- Device ID
- Device type (sensor, retranslation element, etc.)
- Event timestamp in real time
- Status (occupied / free) of the parking space
- Operating status of system components (status) - frequency 1 x per hour (including sensors´ battery voltage)
- Transmission time identifier

However, the central system may contain more data sent to it by the Nodes. Depending on the specified system architecture, it may be agreed between the ordering party and the system vendor that nodes will provide extended data (beyond the data above). Prior to implementation, a list of all the data that Nodes can provide to the Central System (Server) should be provided.

Data from each Node should be sent at least every 1 minute.



Scheme 4: Scheme of data in central system

5.3.2 Possible Central System Architectures

In principle, it is possible to access the Central Server architecture in these ways:

1) Data integration from the system vendor's cloud solution
2) Separate evaluation software that processes raw data produced by Nodes
3) Payment gateway communication - Secure external server

AD 1. Data integration from a cloud solution. It can be agreed that a system vendor will evaluate data from each Node on its infrastructure, e.g. in a cloud environment. In this case, an open data format can be used for communication between the Central System (Server) and the Client's IT Infrastructure, which will be documented in detail by the system vendor. For example, an XML format is considered a suitable solution. The XML file with the measured data behind the completed measuring interval should be periodically automatically generated and stored at the agreed location in the Central System.

AD 2. Separate evaluation SW. With this architecture, all raw data from the Nodes is passed directly to the Central System. The client of such a system wants to run its SW for processing and subsequent publication of data in its environment. In this solution, the SW must be documented in detail, and after implementation, all source data and license keys have been provided to the application by the system vendor.

More detailed technical specifications for the operation of the Central System are given in Annex 2 to this document.

AD 3. Communication with a payment gateway. When making payments across different media (vending machines, mobile or web applications) it is recommended to use different payment methods. Above all, it is possible to use contactless payment cards. This feature can be implemented via secure communication with an external server - a payment gateway.

5.4 Application layer

This part of the system is very important from the point of view of the user. This layer should be paired with data from other systems at the level of the Central System. At this level, it is always important to know the purpose of the resulting solution, the target function of the application. The key applications of the Smart Parking system include:

- User enforcement application
- Mobile and web apps for end users
- Displaying information on VMS
- Supervision of payment discipline
- Demand based charging system (flexible tariff)
- Payment location system for specific areas (mobility fund)
- Management of terminal equipment (payment terminals / vending machines, barrier systems)
- Residential parking system
- Analysis of historical data
- Test applications (e.g. C-ITS systems)
- Interface for sharing with other systems

5.4.1 User enforcement application

The User Enforcement Application is used in the overall system for Information and Control Center staff who have a total overview of at least:

- Occupancy status of locations equipped with smart parking
- Status of all connected components in the system (barrier systems, payment machines, Gates / Slaves, detectors, etc.)
- An overview of all payments made
- An overview of the particular occupied parking spaces that are no longer paid or not paid at all
- Overview of turnaround of parking places in individual zones, areas

- User Enforcement applications should be implemented over maps and specific parking spaces should be differentiated in color (free, occupied and paid, occupied and unpaid, detector unavailable, fault detector)

A User Enforcement application should not only be for a single purpose, but should be part of the overall surveillance module (including transport data, other sensors in the concept of smart cities, etc.) in the case of implementation in urban information and control centers.

5.4.2 Mobile and web applications

Mobile applications are currently one of the most important platforms for customer communication. Mobile applications will in the future play a significant role in the mobility of the population not only in urban areas. The trends of data sharing between systems and the use of mobile phones and applications to use different modes of transport are increasingly being applied. For smart parking, mobile apps should have at least the following services:

- Registration of an application user - in particular vehicle license plate registration
- Tariff information in specific locations / zones / regions
- Possibility to pay for parking in a particular zone / area for an optional duration according to the tariff
- Payment via the payment gateway (e.g. MasterPass, bank cards, etc.)
- Possibility to extend the parking time (it is not necessary to be near the vehicle, remote payments)
- It is a good idea to navigate with the following features:
    - Navigate to a free parking space
    - Finding the nearest vacant space in the destination
    - Recommendation of an ideal way to travel to a location with free parking capacities

5.4.3 Displaying information on VMS

While it may seem that information boards at the time of mobile apps are a matter of history, the opposite is true. Information boards (Variable message signs, VMS) displaying information on availability and price of parking or levels of air pollution act as a necessary source of information for drivers to enter a specific location. In addition to this daily, "communication campaign", information boards located mostly at the edge of zones (e.g. parking zones) can also be used to navigate / divert traffic in the event of traffic jams, technical accidents or other events, of course provided the individual imaging technologies are adapted (the size of the LED matrix, the possible number of displayed symbols, etc.).

Figure 16 Information boards of parking place occupancy place dat the entrance to the zone; the information provided avoid cruising

5.4.4 Supervision of Payment discipline

The biggest problem of many Central Europe cities in the area of parking is the payment discipline. According to Czech surveys, the willingness to pay for parking is between 25-39%.

Effective supervision is the primary tool of any system. Occupancy detectors are only a tool and data source. It is necessary that these data work effectively with the intention to increase payment discipline. The most appropriate measure is a combination of soft surveillance (first offense, user only warned) and hard supervision (fine). A very frequent case of malfunctioning supervision of payment discipline in the Czech Republic is lack of motivation. Supervision employees have no direct link to the parking charging and the whole system. The lack of a relationship "I do not pay for parking, I get a fine" leads not only to the overloading of the street area but also to the motivation of the drivers to use their cars for their driving to the central areas, which secondary impact on the traffic density and the city budget. Therefore, it is recommended that the funds gained from the parking system be at least partly returned to the transport infrastructure or Smart Mobility applications.

The easiest way to control the payment for parking is to use the key data - vehicle license plate. However, the license plate of the vehicle must be entered when the payment is made in all available terminal equipment:

- Payment terminals / vending machines
- Mobile and web applications
- In resident parking management

After the payment has been made, the license plate of the vehicle is introduced in the information system until the parking is paid.

This data can be shared with a console (tablet, mobile phone, etc.) that supervisors can always carry. When checking vehicles, they can get information in a very short time whether a vehicle with a specific license plate paid for parking and how much time is left.

Supervisors may also receive specific information from the system, which places are occupied by vehicles that have already expired parking time, or have not paid for parking at all. However, this system depends on the information about the occupancy of specific parking spaces.

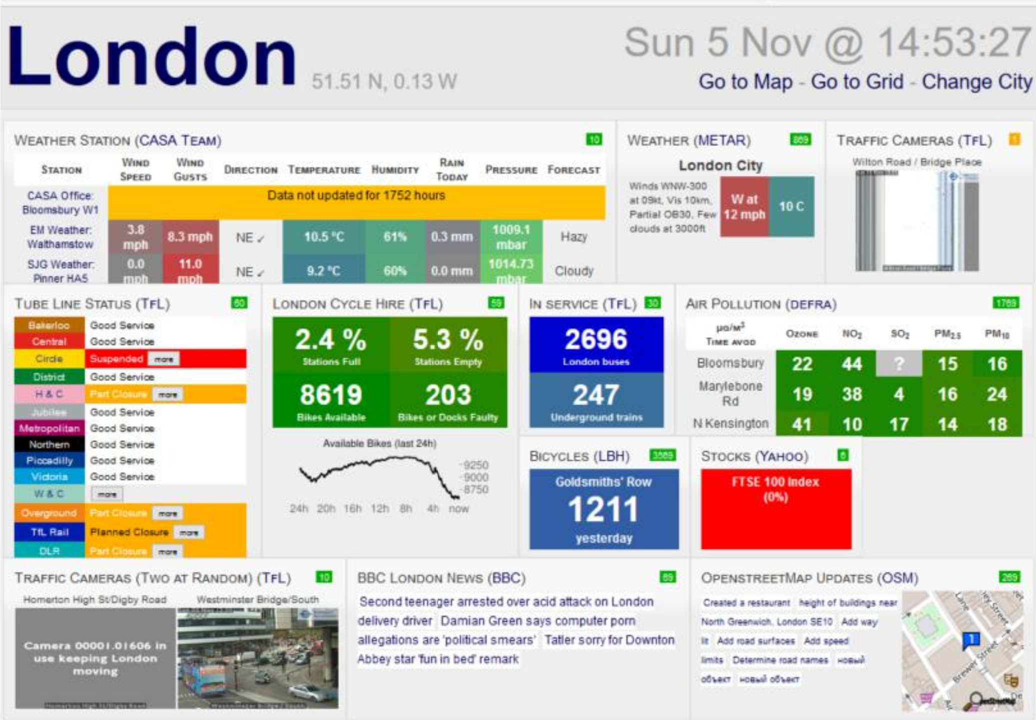
The system of supervision can be implemented in an automated way in the parking zones (charged areas, e.g. residential areas); a special surveillance (enforcement) vehicle equipped with a license plate reding cameras (ANPR) reading cruise around. It captures all license plates of the parking vehicle and compares it with data from the Central System.

Figure 17: Enforcement vehicle surveilling payment discipline in Prague

5.4.5 Data Sharing Interface

For day-to-day operational decision-making of politicians, officials or staff of the city companies, statistical data is also the absolute basis. Data is also important for mobile application developers or other third-party services. That's why every smart city sets up its data portals, where data for developers and other parties are placed as open and machine-readable. That is why the dashboard serves for city and other operating staff.

All data from the Smart Parking System or similar systems, in addition to the central processing, as below, should be available to third parties on the city data portal and also processed into information that should be presented on the city dashboard.



Obrázek 19: City dashboard of London city good practice case

5.5 Summary of Chapter

In its basic form, the system provides anonymous detection of occupancy of parking spaces for parking operators. The basic system is used to deploy selected parking spaces by means of vehicle presence detection technologies, allowing for on-line monitoring (occupancy of a particular parking space, percentage of parking capacity, etc.). In order to manage the parking system, on the basis of a continuous collection of parking space occupancy data, the system presented will automatically offer the possibility of long-term parking evaluation for the purposes of adjusting the tariff policy, or, for example, comparing and quantifying the difference in parking payments between the currently running system (data from payment terminals) and smart parking system (real-time parking data).

In more advanced forms of the system, it will enable drivers to drive their cars to free lots, pre-trip information through a special web application, or on-trip by VMS or mobile applications. Occupancy data may also be offered to navigation or traffic data providers to use them in developing related passenger services to the public.

In its full form, it will allow drivers to pay by electronic means (e.g. bank cards, mobile phones, city cards) for real time parking. Such a system is, of course, much more complex and much more expensive than basic one, but thanks to the modularity of the smart parking system, it can be built up gradually.

6 Data management system part 2: Identification of the sources of pollution and their detection

6.1 Generaly

Deploying sensor networks gives the ability to assess the level of air pollution in locations where traffic interacts with parking. By linking traffic flow monitoring data and air pollution monitoring data, according to the proposed system in the document, it will be possible to monitor and evaluate the ambient air quality in selected urban agglomerations.

The document describes a TBMS system (Traffic burden monitoring system) that enables cities to fulfill their commitment based on the European Union Air Quality Directive[4].

The Directive consolidated a number of earlier directives and sets objectives for several pollutants which are harmful to human health.

It requires Member States to:

- **Monitor and assess** air quality to ensure that it meets these objectives;
- **Report** to the Commission and the public on the results of this monitoring and assessment;
- **Prepare and implement** air quality plans containing measures to achieve the objectives.

The commitment is divided into several levels:

6.1.1 Strategic level

- Linking sensor technologies to the city-agglomeration sensor network (IoT) will support the following measures, which are part of the agglomeration air quality improvement plans:
  - Deployment of reduced speed zones in selected parts of the city
  - Parking regulation

Due to the availability of air quality data, it will be possible to:

- Set up the next steps of regulation if air quality is insufficient
- Assess compliance with the set actions
- Establish long-term visions

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6.1.2 Information level

Innovative sensor technology enables to:

- Extend the existing small density of the measuring stations
- Support sufficient monitoring at selected locations
- Support enough current data in open format
- Promote enhanced data delivery to the public through open format and availability of new applications

6.1.3 Fulfilment of EU requirements on Member States

- The above mentioned requirements for the Member States

This document on a complex system (TBMS) enables to comply with all the three requirements as the designed concept supported by technologies of Internet of Things (IoT) provide continuous and detailed air quality monitoring.

6.1.4 Crucial process problems in air quality management in EU

Besides the policy requirements some crucial problems in the whole process have been identified:

6.1.4.1 Policy level

- **Air quality plans are lacking of true solutions**, timeline and impact strategy, lack of long term vision and strategic goals, lack of synergic planning with other initiatives
- If the air quality levels are breached **there are no consecutive obligatory steps** to solve the problem, legal proceedings are delayed as legal actions can take several years to reach a conclusion

6.1.4.2 Information level: lack of information

- **low density** of air quality measurement stations in cities,
- **lack of monitoring** on the most congested places,
- **inconsistency** between “official” air quality data and other “unofficial” data
- **lack of up-to-date information**, with data published a long time after breaches of limit values have occurred
- **technical presentation** of the measured data with low potential of public understanding
- **No “on trip” alerts** given to travellers, no warnings
- **No information on commitment** to achieve better air quality and the regular improvement status, lack of measures implementation and their real impacts

6.1.4.3 Involvement level

- **Citizens involvement** in Air quality action plan formulation is low, air quality is not a public topic to be discussed

6.1.4.4 Air quality levels – limit values

This standard proposes specific actions to be taken when levels of air pollutions are rising (far before it is breached). The standard also proposes the actions when the daily or year limits are broken.

The strictest type of air quality objectives contained in the Directive [3] are known as "limit values." Limit values are set for:

- Particulate Matter (PM10 and PM2.5)
- Sulphur Dioxide (SO2)
- Nitrogen Dioxide (NO2)
- Lead
- Benzene
- Carbon Monoxide

Limit values are informed by guidelines set by the World Health Organisation (WHO). However, in the case of PM10 and PM2.5, the limits are considerably higher (i.e. less stringent) than the WHO recommendations.

Pollutant	Obligation	Time period	Compliance deadline	Permitted annual exceedences
Nitrogen dioxide (NO_2)	Hourly limit value of 200 µg/m3	1 hour	01/01/2010 (possible extension to latest 1/1 2015)	No more than 18
	Annual mean limit value of 40 µg/m3	Calendar year		n/a
Coarse particulate matter (PM_{10})	Daily limit value of 50 µg/m3	24 hours	01/01/2005 (possible extension to latest 1/6 2011)	No more than 35
	Annual mean limit value of 40 µg/m3	Calendar year		n/a
	Annual mean limit value of 25 µg/m3	Calendar year	1/1/2015	n/a
Benzene	Annual mean limit value of 5 µg/m3	Calendar year		

Table 5: – The limits defined by the Directive2008/50/EC [5]

6.1.5 Air pollution sources

Air pollution is caused by a variety of polluting matters from various sources (see table B.1 in the annex B). One of the main sources of city air pollution is traffic. Traffic emits various harmful matters, not just by combustion engines of cars and

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other vehicles but also so called non combustion pollutants including particles derived by road surface abrasion, abrasion of tyres, mechanical components abrasion (braking pads, clutch lining) and also by resuspension of dust laid on the road by the traffic. So it is very hard to clearly identify the source of a particular matter as it can be emitted into ambient air by various sources. **However the following pollutants related to traffic can be considered: nitrogen oxides, benzene, platinum metals and ultrafine dust particles. So air quality related to traffic can be monitored by occurrence of these matters.**

Basic matter to be monitored are **Nitrogen oxides** (NO, NO_2, NO_x) as they are emitted to the ambient air by all the high temperature combustion engines where fossil fuels are combusted at the temperatures higher than 1 300°C. In urban environment the traffic is the dominant source of the pollutants except the areas with specific industry processes (like producing Nitric acid). The other two pollutants to be considered are **dust particles and benzene**.

6.1.5.1 Nitrogen oxides

Nitrogen oxides (NO, NO2, NOx) are emitted into the atmosphere by all high-temperature combustion processes, where fossil fuels are fired in the air at temperatures above approx. 1 300 °C. In urban environments, **transport is the dominant source of this group of pollutants, with the exception of areas with specific industrial processes** (eg nitric acid processing). The measurement of concentrations of these pollutants is methodically well defined and managed and is relatively simple even in the continuous measurement of air quality. The reference method for the measurement of NO, NO_2 and NOx concentrations is chemiluminescence based on excitation of nitric oxide molecules with ozone (EN 14211). When transferring molecules from the excited to the basic energetic state, the yellow-green chemiluminescence radiation, which is detected by the photomultiplier, is released. In this way, the NO concentrations can be measured directly. If a gas sample is passed through a molybdenum converter in which NO_2 is reduced to NO, the total NOx concentration can result from the chemiluminescence measurement. The concentration of NO_2 is then calculated from the difference in NO and NOx concentrations. The method makes it possible to determine the instant concentrations of nitrogen oxides in the air and is highly selective since the other air components do not exhibit chemiluminescence at this wavelength. Radiation intensity is a linear function of concentration within a wide range of several orders.

Monitoring of nitrogen oxides can be built on continuous measurements, which makes it an effective tool for day-to-day operation of the city.

6.1.5.2 Particle matters

Solid particles (PM), unlike other pollutants, are not a specific chemical unit, but they are a mixture of particles from different sources, of different sizes, composition and properties. PMs include particles of solid and liquid material ranging from 1nm to 100μm, which remain for some time in the air (US EPA, 2004a). In the atmosphere we encounter them in the form of a complex heterogeneous mixture in terms of particle size and their chemical composition. Suspended solid particles are characterized by their specific physical (shape, size, electrical charge, particle surface and solubility) and chemical properties (inorganic and organic components) that are predetermined by their source, mechanism of formation and other conditions affecting their origin (distance from sources, meteorological conditions). All of the above is the cause of the complexity of measuring PM concentrations, namely that it is necessary to pre-select the method of measuring concentrations depending on how large the particles are the object of our interest and what particle characteristics we want to find out. As a result of transport traffic, the whole particle size spectrum is generated, as a coarse fraction of PM2,5-10 (the dusting of road dust and the surrounding environment, tire wear, road surface, partial combustion processes), fine PM2,5 fractions (especially combustion of fuels, less road and road surface abrasions). Incineration processes in car engines then produce especially ultra-fine particles PM0,01 (nanoparticles), which are essentially the only source of pollution in the urban environment. However, these particles can also originate from gaseous pollutants in the atmosphere (i.e. by coagulation from gaseous precursors in the atmosphere), thereby increasing their measured concentrations. Measurement of the concentrations of such small particles is based on the determination of their number and places great emphasis on the accuracy of the measuring technique, with which the purchase price and operating costs are related. For measurements of concentrations of large-scale particles, it is also possible to use devices based on the principle of nephelometry, i.e. laser beam scattering. Instruments working on this principle make it possible to determine the mass concentrations of PM10, PM4.0, PM2.5, PM1.0 and count concentrations at various size intervals, usually in the range of 150 nm to 32 μm (size range may vary depending on manufacturers of the device). For long-term routine monitoring, this type of measurement is more advantageous, however it is important to keep in mind above mentined facts.

Thus, solid particle monitoring can be built on **continuous measurement**, making it an **effective tool for operational day-to-day operations.**

6.1.5.3 Benzene

Benzene is produced by combustion of fossil fuels and is also released by volatilization from petrol from the fuel tank or during refueling and in specific industrial processes (oil and gas refineries, combustion of fuels (coal, oil). The benzene in gas mixtures may be based on a variety of methods based on different principles, depending on the aim of the analysis and the analyte amount in the gas. The sampling and analysis of benzene in the ambient air is based on sorption of benzene in the sorption tube, thermal desorption and capillary gas chromatography (these are reference methods for the determination of benzene in ambient air of the European Union given in EN 14662, for the purpose of comparing measurement results with specified annual limit values). This European Standard lists several variants of the procedure. The most suitable sampling of the sample for long term air quality monitoring is by sorption tube followed by gas chromatography analysis (EN 14622-3), which can be realized in the operation of one instrument.

Benzene monitoring can thus be built on **continuous measurement**, making it a powerful tool for **operational measures of the city on an annual basis**.

6.1.6 Monitoring by environmental sensors´ network

The Directive 2008/50/EC lays down rules on:

- the minimum number of monitoring stations; and
- where they must be located.

These rules on monitoring and assessment, while very complex, are insufficient to ensure full and accurate assessment of air quality. Monitoring stations are to be sited at locations which are representative of the highest levels of pollution in a zone or agglomeration. However, in practice, this provision is often ignored or abused by member states. Monitoring stations are frequently placed in areas which do not have the highest levels of pollution.

More commonly, Member States fail to publish or report data from unofficial monitoring sites that are not part of their official network. Often this will be justified on the basis that the unofficial data does not meet the very detailed siting requirements of the Directive, for example because the monitoring station is too close to a road junction. These problems arise in part because the Directive does not require sufficient monitoring stations, allowing member states to use modelling techniques to supplement monitoring data. While modelling provides useful supplemental information and reduces the need for expensive monitoring stations, it is not always accurate and is open to manipulation by Member States.

6.2 Air quality ITS station

The air quality ITS station used for the long-term monitoring of air quality with regard to the expected source of transport pollutants should therefore, on the basis of the above, be capable of stable and accurate measuring of the concentrations of nitrogen oxides using the reference method (EN 14211). For the purpose of refining the information, the station may be extended by a benzene concentration measurement device, again operating on the reference method (EN 14622-3) and a particle count instrument operating on the nephelometry principle. In the case of measurement of solid particle concentrations by the nephelometry method, the validation of this method should be performed on a regular basis by comparing the results obtained with the results determined by the reference method defined in EN 12341. The measurement of air pollutant concentrations should also include measurement of meteorological parameters including temperature, direction and wind speed.

With regard to the needs of city implementing the air quality measurement, the AG ITS-S stations can be divided into three types according to the instrumentation (see Table 2). Of course, the station equipment is associated with the costs of acquiring the station itself and the cost of operating it, including instrument calibration, energy consumption, trained personnel, etc. Prices for devices do not include the cost of housing and air conditioning. Operational and maintenance costs do not include the cost of electricity, including only one-year calibration costs and regular annual service. All listed prices are very approximate and may vary significantly depending on the instrument manufacturer, the prices of the relevant calibration laboratory, the prices of electric energy, etc. Generally in all parameters (i.e. purchase, operation - calibration 1 times a year, maintenance - regular annual service) the price rises from a less equipped station (class C) to a full-equipped station (class A).

AG ITS-S class	**Measured pollutant**	**Measuring method**	**Total cost comparison by the variable *x***	
			purchase	**Operation and maintenance (year)**
A	Nitrogen oxide concentration	chemiluminiscence (EN 14211)	50x	2,5x
	Particle matter concentration	nefelometry		
	Benzene concentration	gas chromatography, automatic sampling by sorption tube (EN		

		14622-3)		
	Meteorology parameters	Common methods		
B	Nitrogen oxide concentratio n	chemiluminiscence (EN 14211)	30x	2x
	Particle matter concentratio n	nefelometry		
	Meteorology parameters	Common methods		
C	Nitrogen oxide concentratio n	chemiluminiscence (EN 14211)	13x	x
	Meteorology parameters	Common methods		

Table 6: Classification of Air Quality ITS stations (AG ITS-S), the reference methods and the cost comparison (

6.2.1 Pollutants values, index and scenarios

The instruments used shall be capable of delivering concentrations of the relevant pollutant in at least ten minute intervals in order to determine hourly averages which may be related to the limit concentrations defined in Directive 2008/50/EC. In order to regulate the traffic according to the current air quality situation, concentrations of NO_2 and, where appropriate, concentrations of particulate matter PM10, which have a defined hourly limit value of 200 μg.m^{-3} in the case of NO_2 or daily limit value of 50 μg.m^{-3} for PM10. However, it should be borne in mind that **PM10** does not come exclusively from transport but is produced by a wide range of sources and therefore their concentration should serve **as an indicator of pollution**. The proposed quantification of numerical concentrations of ultra-fine particles reflects transport pollution more, but there is no air quality limit to this characteristic defined and its definition is very difficult.The actual air quality assessment can be based on the indices defined by the Czech Hydrometeorological Institute (see Table 3). The calculation of the air quality index, which takes into account the possible impact of air quality on the health status of the population, is based on the evaluation of 1h concentrations of nitrogen dioxide (NO_2) and particulate matter (PM10). In the calculation, 1h average concentrations are used for PM10 as they better outline the current status (1h concentration limits were derived based on statistical analysis between 24h and 1h concentrations).

index	Air quality	Measure/Action	NO_2	PM10	Benzen
1	very good	No action	0 - 25	0 - 20	0-2
2	good	No action	> 25 - 50	> 20 - 40	2-3
3	satisfactory	scenario 1	> 50 - 100	> 40 - 70	3-4
4	acceptable	scenario 2	> 100 - 200	> 70 - 90	4-5
5	bad	scenario 3	> 200 - 400	> 90 - 180	5-6
6	very bad	scenario 4	> 400	> 180	> 6

Table 7 - Air quality index and individual limits for selected pollutants

In the case of monitoring traffic-based air pollution, stations should be located in accordance with Directive [3] and Directive [10] that clearly define the location of sampling and measuring devices in relation to road.

6.2.2 Performance requirements, installation, operation and maintenance of AQ ITS station

An air quality ITS station used for the long-term monitoring of air quality with regard to the supposed source of traffic pollutants should be capable of stable and accurate measuring of the concentrations of nitrogen oxides using the reference method (EN 14211), that is, Class C stations. For the purpose of refining the information, the station may be extended by a benzene concentration measurement device, again operating on the reference method (EN 14622-3) and a particle count instrument operating on the nephelometry principle.

Directive [6]defines requirements on the measurement uncertainty, which are for long-term stationary measurements stated as 15 % for nitrogen oxides, 25 % for benzene and 25 % for PM (for the reference method of measurement, which is gravimetry). In the case of measurement of solid particle concentrations by the nephelometry method, the validation of this method should be performed at regular intervals by comparing the results obtained with the results determined by the reference method according to EN 12341.

Instruments should be regularly serviced at least annually and calibrated at the calibration laboratory or by calibration standard of the calibration laboratory at the same interval. Regular verification of the correctness of the measurement within the range of at least 0 and one measured value with a calibration gas of known concentration in the range of approximately 14 days.

6.3 Summary of the Air Status Monitoring Chapter

6

Instead of providing free public transport for smog situations, which is an example of current practice and ineffective city policy, it is appropriate to take action on polluters. In the field of transport, it is the driver of cars and trucks. Continuous monitoring of occupancy of parking spaces and a flexible tariff together with information on air quality in a given location allow the city to introduce, for example, in the case of smog situations, e.g. double parking price or to otherwise regulate the supply. Such measures may additionally be triggered semi-automatically, i.e., there is no need for a city council decisio.

7 Parking regulation scheme – case

The chapter consolidates informations from previous chapters and helps you to decide which case you will choose as a pilot implementation.

Before you will choose which area of the city/ con urban area you would like to solve. It has to be taking in to account that the integration of data from larger scale of detection technologies and subsystems into a single SW module with information and control potential enables to design new traffic measures on the basis of actual information on air quality, traffic intensities or weather conditions.

After that, you may come up with completely new motivation or gamification schemes that smart tool allows with the aim to increase acceptability and reducing adverse side effects of LEZ and other access restriction policies.

Therefore pilot and lighthouse projects can be initiators becoming testing grounds of a new parking regulation scheme.

The following structure can help you with decision making survey on suitable technologies for specific case.

P  nalytical part

S lity

d g urban and sub-urban strategies

D rt of existing infrastructure

S ives of introducing smart parking tool in

s (Chapter 4.2)

P  etection and transmision layers

S ensor technology for quantifycations of the

c r a parking space (Chapter 4.3)

S arking sensor technology (Chapter 5)

S Q sensor (Chapter 6)

Phase 3 Evaluation and aplication layers

C m network (Chapter 5.4)

A (Chapter 6.1)

7.1 Use Cases of Parking regulation scheme

7.1.1 Use Case 1 _ regulation on street parking

A municipality wants to deploy its parking policy based on real parking demand in its central location. In the neighbourhood of the centre there are two parking houses or places with the limited use which is caused by higher price of the off street parking to the on street parking in the adjacent streets. More the central part of the city is highly occupied with cars which causes cruising when searching for a free parking bay and makes the traffic denser. The city wants to change this pattern and move the cars to the parking houses. This is to be done partly by payment regulation adjustment and partly by better enforcement thanks to the whole area deployment of a smart on street parking system. The city also wants to provide incentives to handicapped or eco-friendly car users and dedicate several parking bays just for them.

B. Objective 2: Detection of parking capacities´ occupancy

B.2 Scenario: Toll parking

The following table summarize the steps of digital passport. More information concerning each stage you can find in chapters on this document.

Stage	Step/ Nr chapter	Action	
Specification of an area	1 Passport of the parking bays and area in relation to the infrastructure/ 4.1.2	Urban parking sity type	Off street parking On street parkign Other parking as associated with some other location
		Name	Street, location
		Parking number of space	Maximum of space for area
		The parking space is marked with road marking	Type of echelon parking Parking spaces are located in a diagonal relation to the road.
			Parking spaces are located parallel to the road

Stage	Step/ Nr chapter	Action	
			Parking spaces are located in an angle of nearly 90 degree to the road
		The border of the parking space is not marked	Maximum parking space
		Geographic conditions 4.1.1. C	Topography
		Road surface	Asphalt pavement
			Cobblestones
			Concrete pavement
	1. Passport of the parking bays and area in relation to the transportation	Occupancy, turnover	
		Capacity of resident parking	
		Parking prohibited	
		Vehicle characteristics	Amount of goods vehicles
	Passport of the parking bays and area in relation to the parking house	Parking owner	
		Security service	
		Operator	
		Parking layout	Open space Single level Automated parking garage
		Parking service facility	type of equipment or additional service facility that is available at the parking site, parking space or group of parking space
		Maximum parking duration	Long Term Short Term Pick-up drop-off
Detection layer	2 Passport of the ITS deployment 5.1.9	Parking occupancy detection	Type of parking occupancy detection for a parking record, a parking space or a group of parking spaces, if any
			Single space detection
		Monitoring of pollution values	
		Traffic sensors	Cameras at the

Stage	Step/ Nr chapter	Action	
			intersections, induction loops, strategic detectors etc.
		Tariffs and Payment	On line terminals, RFID
Specification of Network	3. Passport of the communication layer 5.2		

Table 8: Digital passport for B objective, Scenario B2

The crucial terms are the following:

The city should have the static data in digital form which means a standard description of the parking bays and areas as the first step for smart on street parking system deployment.

The city should demand the standard data provision from parking houses operators. Both is provided in DATEX II format.

7.1.2 Use Case 2_ regulation parking near by ZTL

A municipality wants to enhance its parking policy around the zone where access traffic regulations are implemented to avoid car cruising when finding place for parking in front of the zone. In the neighbourhood of the zone or the city centre there are on street parking and off street parking areas. The city wants to offer the drivers an alternative way of travelling into the zone and navigate drivers to particular parking facilities within this area.

B. Objective 2: Detection of parking capacities´ occupancy

B.1 Scenario: Real-time transfer of parking capacity information to the drivers by means of application or variable message signs

B.2 Scenario: Toll parking

The following table summarize the steps that might be taken before implementing smart parking tool regarding that case.

Stage	Step/ Nr chapter	Atributes	
Mapping traffic	1	Types of roads and their proportions	Use the Street Types categories to map the area, identify the proportion of each type
Data collection and analysis	2	Existing survey data	Traffic data
Specification of strategies	3 Survey of existing urban and sub-urban strategies. 4.1.1. A	Specific measures for roads, zones	
Specification of an area	4 Passport of the parking bays and area in relation to the infrastructure/ 4.1.2	Urban parking site type	Off street parking On street parking Other parking as associated with another location
		Name	Street, location
		number of parking spaces	Maximum of space for area
		The parking space is	Type of echelon parking

Stage	Step/ Nr chapter	Atributes	
		marked with road marking	Parking spaces are located in a diagonal relation to the road.
			Parking spaces are located parallel to the road
			Parking spaces are located in an angle of nearly 90 degree to the road
		The parking space is not marked	Maximum parking space
		Geographic conditions 4.1.1. C	Topography
		Road surface	Asphalt pavement
			Cobblestones
			Concrete pavement
	4 Passport of the parking bays and area in relation to the transportation at the area	Occcupancy, turnover	
		Capacity of residents parking	
		Parking prohibited	
		Vehicle characteristics	Amount of goods vehicles
		Maximum parking duration	Long Term Short Term Pick-up drop-off
Detection layer	5 Passport of the ITS deployment 5.1.9	Parking occupancy detection	Type of parking occupancy detection for a parking record, a parking space or a group of parking spaces, if any
			Single space detection
		VMS	
		Traffic sensors	Cameras at the intersections, induction loops, strategic detectors

Stage	Step/ Nr chapter	Atributes	
			etc.
		Tariffs and Payment	On line machine , RFID
		Monitoring of pollution values	Air quality sensors
Specification of Network	6 Passport of the communication layer 5.2	Networks	

Table 9: Digital passport for B Objective, Scenario B1 Regulation parking near by ZTL

7.1.3 Use Case 3_ regulation P+R

A municipality wants to regulate commuting to the central zones of the city and therefore public transport stations and nodes in conurban areas should be equipped to serve as intermodal or multimodal hubs of sustainable transport modes. The parking areas should be equipped with a smart on street parking tool.

Park and Ride facilities provide an opportunity for car drivers to exchange to a high-occupancy mode such as rail, LRT (Light Rail Transit) or bus for onward travel. The objectives of Park and Ride are more varied and should be carefully considered by the City and key stakeholders during the development of a Park and Ride strategy. Objectives should be focused on reducing the number of vehicle/km travelled within the city and extending the reach of the transit system to lower density areas which are not well served by transit, whilst protecting local residents living near a transit station from traffic and overflow parking. Furthermore travelers need to be informed about real information concerning to occupancy of parking lots. Park and Ride facilities should be equipped by a smart parking tool.

B. Objective 2: Detection of parking capacities´ occupancy

B.1 Scenario: Real-time transfer of parking capacity information to the drivers by means of application or variable message signs

The following table summarize the steps that might be taken before implementing smart parking tool regarding that case.

Stage	Step/ Nr chapter	Action	
Specification of an area Detection layer	1 Passport of the parking bays and area in relation to the infrastructure/ 4.1.2	Name	Stop point location
		Number of parking spaces	Maximum of spaces for area
		The parking space is marked with road marking	Parking spaces are located in a diagonal relation to the road.
			Parking spaces are located parallel to the road
			Parking spaces are located in an angle of nearly 90 degree to the road
		The parking space is not marked	Maximum parking space
		Geographic	Topography

Stage	Step/ Nr chapter	Action	
		conditions 4.1.1. C	
		Road surface	Asphalt pavement
			Cobblestones
			Concrete pavement
	1. Passport of the parking bays and area in relation to the transportation	Occcupancy, turnover	
	1.Passport of the parking bays	Parking owner	
		Security service	
		Operator	
	2 Passport of the ITS deployment 5.1.9	Type of parking occupancy detection if any	Cameras, sensors
		Monitoring of pollution parametrs if any	
		Tariffs and Payment	On line terminals, RFID
Specification of Network	4. Passport of the communication layer 5.2		

Table 10: Digital passport for B Objective, scenarion B1 regulation P+R

7.1.4 Use Case 4 _ parking regulation concerning

A stakeholders wants to regulate parking policy based on interconnected data from the sensor network.

A. Objective 1: Traffic Burden Monitoring (Traffic Burden Monitoring System, TBMS)

A.2 Scenario: Sensor technology monitors the air quality locally.

The table 7 below specifies the parking measures that should be triggered as the actions for improving air quality when the thresholds (not EU thresholds) are overstepped. The policy based on such a scheme can provide "semi-automated" actions without the need of operational political decision making process or operational schemes of city companies that do the cleaning of the streets. As each measure is classified and connected with a specific benefit and a specific triggered action/scenario the city policy can react on the actual as well as long term levels of air pollution. So the bridge between air quality measurement systems deployment and specific reactions of a city is established. Such a city can communicate the impacts of the policy on traffic burden to the public in a consistent way so the overall acceptance can be achieved. More the transparency of the process based on open data provided by TBMS enables to evaluate the policy results in specific numbers for a particular area and as such provide a city government with arguments for related investments as well as fulfilment of strategic goals. TBMS with AQ ITS stations network can also provide the city with approximate values of traffic based air pollution and derive the achievable targets for a specific area.

This document provides a guidance how such a parkig policy can be established so it is fully up to a stakeholders to create its own air quality policy scenarios based on the air quality measures and actions below regarding local feasibility of the actions. The stakeholders itself should specify the time limit, e.g. 1 hour/day of continuously overstepped threshold value, to trigger an action for real time values and real time actions.

Scenario	Air quality level	Types of actions
Index 3: Scenario 1	Satisfactory	parking zones design with long term target air quality goals, complementary tree planting, resident questionnaires, basic scenario of street cleaning
Index 4: Scenario 2	Acceptable	Parking zones introduction with residential parking, Geofencing technologies deployment, sharing concepts deployment

Index 5: Scenario 3	Bad	Plan for Toll introduction or strict parking regulation deployment
Index 6: Scenario 4	Very bad	Very strict traffic regulation, high prices for parking, toll introduction, ban for Euro 3 and lower vehicle classes

Table 11: Typology of TBM objective, typ of scenarios

Specific measures can be applied to specific streets / areas of the Function Urban Areas, taking into account spatial and technological possibilities. A list of specific measures will be defined by a European Standard prepared under CEN / TC 278 Intelligent Transport Systems.

8 Source / Future literature

Richard W. Willson, Parking Management for Smart Growth, 2015

Richard W. Willson and Donald c. Shoup, Parking Reform Made Easy, 2013

Donald C. Shoup, The High Cost of Free Parking, 2015