Traffic Burden Monitoring Systems
as a solution for tackling air quality in European cities

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Air quality is a major problem of European cities. To solve the problem a strategical approach based on continuous data from deployed modern technologies should be used. The traffic burden monitoring system is a new way of monitoring air quality in a city in a needed scale and resolution and can provide data that can become a game changer for the city as well as people decision making.

1. Introduction

The most recent directive relating to ambient (outdoor) air quality is the Air Quality Directive (2008/50/EC [1]), which was adopted in 2008. 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.

To make air quality plans really functional the city should take actions in near real time by a set of pre-defined measures and take pre-defined strategic actions based on yearly evaluation. This is to be achieved by continuous monitoring of reliable sensor-based networks.

The findings presented have been gained within the project SmartNet [4] and the project SOLEZ [3].

2. Air pollution sources

Air pollution is caused by a variety of polluting matters from various sources. One of the main sources of city air pollution is traffic. Traffic emits various harmful compounds, not just by combustion engines of cars and other vehicles but also by 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 particles. So air quality related to traffic can be monitored by occurrence of these pollutants.*

Basic pollutants to be monitored are nitrogen oxides (NO, NO_2, NO_x) as it is emitted to the ambient air by all the high temperature combustion engines where fossil fuels are combusted at the temperatures higher than 1300°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 due to the affordable cost of monitoring are particulate matter and benzene.

3. Strategies and technologies

The rise of new technologies, mainly based on Internet of Things (IoT), brings new potentials to traffic management and its environmental impact on quality of life in cities. The cities are buying various sensors or even networks of sensors within their smart cities concept with the risk of unstable or uncertain source of data or even malfunction of the equipment.

Also wrong use of low carbon mobility policies and tools or their non-existence in city policies causes significant negative impacts on citizens´ health as well as low cost efficiency of the potential technologies compatibility and management. The good practice from Amsterdam (parking policy [2]), Barcelona (tactical urbanism) or Vicenza (low emission zone and low carbon city-lead logistics hub) should be spread in connection with suitable technological background [3].

Nowadays technologies for smart parking and/or traffic flow management based on low cost IoT sensors embedded in the ground bring reliable, long term and low cost solution for traffic monitoring in scale. The traffic can be monitored continuously in every street which brings valuable data for decision making of single citizens or city departments e.g. where to buy a flat, where to start a shop or where to decrease the number of parking spaces.

It also provides valuable data of traffic intensities which can be computed to noise and air quality levels.

The reliability of such data can be perceived as high and provides new possibilities to control traffic in an advanced way, enforce dedicated zones with geofencing and parking price regulation, e.g. in the smog event. If the data about traffic burden is provided as open data the city supports bottom-up approach as the citizens themselves will care about the place they live and push the steps for better traffic regulation and improved air quality and the quality of life at their particular place.

On the other hand the technologies for air quality measurement are very tricky. The low cost electrochemical sensors provide inaccurate values for pollutants concentrations as the temperature and humidity changes influence the quality of measurement significantly. After real testing, these sensors have been found unreliable becoming a source of “data noise”, see *Figure 1* [5].

So specifically designed requirements on air quality ITS stations are necessary to enable to deploy systems that are reliable and that provide trustful data for city operational as well as strategical decision making and to prevent public sector from buying non-reliable sensor networks.

4. Technologies deployment – two philosophies of geofencing

The key element of smart cities initiatives consists in measuring the real time status and long term status of the traffic in particular streets and its impacts on environment. As the technology cost is significantly lower due to Internet of Things (IoT) cities invest in sensor networks.

There are two philosophies how to approach the traffic regulation and relevant technologies for geofencing – Traffic Burden Monitoring System (TBMS) and Access Control and Enforcement System (ACES, including active geofencing). The monitoring IoT system (TBMS) enables anonymous low cost continuous mapping of traffic burden in every street of a city; the enforcement system (ACES) is an access control system identifying and charging the access to the zone (city toll, access restriction to low emission zone etc.). The technological solutions of both philosophies differ very much in cost as well as maintenance cost and also in volume of data available and its potential of extension or use. So TBMS is seen as the technological concept that could be spread in every European city with affordable cost.

4.1. Traffic Burden Monitoring System (TBMS)

The monitoring system enables low cost and wide scale coverage of detection of an actual as well as long term traffic burden. Its main contribution is for modelling and planning of adequate air quality measures and actions. It is also a very good system for SUMP purposes. It consists of two parts: traffic monitoring and air quality monitoring.

The traffic monitoring part is an IoT system based on traffic flow detectors (e.g. magnetometers) deployed in every street of the city that enables to count the numbers of vehicles. At the entrance (access roads) to the zone it also enables to gain the length and velocity of the vehicles which improves the information for air quality modelling purposes. The number of vehicles per street can be then modelled into a noise and air quality burden model per street/smaller area of the zone and as such

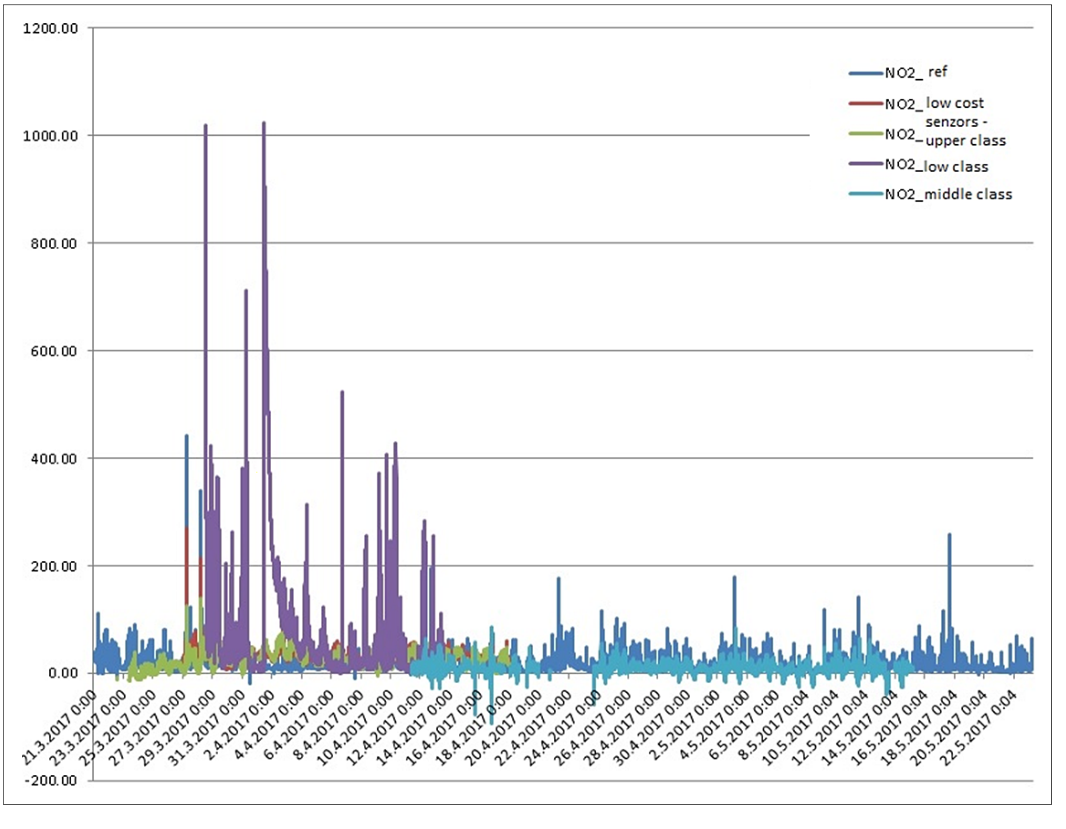

Figure 1. Results of testing several sensors systems for air quality measurement available in the market [4] against each other showing the significant differences among the systems and significant and not acceptable deviations from the air quality reference method (NO2_ref)

helps city decision makers to distinguish the places with urgent need for a set of Air Quality Action Plans (AQAP). City can profit from existing camera network and provide similar data for streets that are already covered by detection.

As the air quality modelling can be very unprecise due to the lack of information about the type of engine and age of passing vehicles, the monitoring system has to be supported by the on-site air quality monitoring. This is done by the deployment of Air Quality ITS stations (AQ ITS-S) of appropriate class *(see Table 1)*. The minimum acceptable class for TBMS is the class C. The advantage of AQ ITS-S network is its mobility so the deployment enables to change the deployment site from time to time and as such to cover an area with dense air quality measurement network. The data from AQ ITS-S network serves for improving the model (historic data analysis), recognizing other sources of pollution (e.g. household heating, industry) and providing valuable data for evaluation of air quality actions and for arguments for public communication.

There are also significant side effects of TBMS deployment. Besides continuous monitoring of traffic in a wider scale that enables to evaluate SUMP or AQAP target achievements, the traffic monitoring continuous data can serve e.g. for politicians´ arguments for residential parking introduction as it can be interpreted in public health impact. The data can also be viewed as big data; together with demographics data it can provide a heat map on where new concepts, e.g. car sharing services, introduction can be successful. The data also serves for better specifying the quality of life at particular places (different traffic burden) and as such can influence the retail and housing estates markets. All this and probably many more issues can significantly contribute to public discussion on sustainable mobility and quality of living and could be a game changer for city sustainable developments and air quality improvements.

The TBMS is the basic system for air quality improvement and can be successfully combined with parking regulation technologies and/or access regulation technologies.

4.2. Traffic flow data conversion into environmental impact – air quality model

Traffic flow data can be used also for air quality assessment, respectively to calculate emissions that contribute to air pollution and are produced by transport in the monitored area.

In general, this is done in the following steps. Firstly, data for the calculation of fleet composition (EURO 0-6) will be prepared based on known dynamic tracking data (e.g. from traffic survey or vehicle count in the area under consideration). Other input data are traffic flow data including traffic intensities of selected vehicle categories (up to 12 cats), traffic flow rates and traffic fluency in model sections. The data can also distinguish the different directions of the flow. Using spatial analysis in the GIS environment, the slope attribute of the communication can be assigned to sections. The following is the calculation of emissions using a particular emission model based on the emission factors of different pollutants (the amount varies depending on the emission model used), both the primary pollutants, solid particles from brake and tire wear, and secondary emissions in the form of dust resuspension. Emission factors for the relevant pollutant are further divided according to several criteria, such as transport categories, fuel used (automotive gasoline, diesel, LPG, CNG), emission standard (conventional drive – EURO 0, EURO 1-6) vehicles should meet. Depending on which emission model is being used, further refinements such as climate data, truckloads can be input into calculations. In the case of detailed modelling of intersections, it is usually possible to enter parameters such as column length, delays at the junction, vehicle speed before and after the junction.

Such an emission model, based on the above procedures, allows a detailed spatial assessment of transport emissions and, in particular, a precise comparison of the current and prospective status.

The result is two basic quantities, namely emissions production (kg/section/day) and emission flow (kg/km/day or g/m/s).

For the traffic burden monitoring system (TBMS), it is possible to use these more detailed data from the system of monitoring the intersections of major roads of the city, which are at the entrance to the defined zone. It is then sufficient to extrapolate these data in the surface monitoring of each street according to the number, length and speed of vehicles.

4.3. Monitoring by environmental sensors´ network

General findings [5]

The Directive [1] 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.**

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
	Particulate matter concentration	nefelometry		
	Benzene concentration	gas chromatography, automatic sampling by sorption tube (EN 14622-3)		
	Meteorology parameters	Common methods		
B	Nitrogen oxide concentration	chemiluminiscence (EN 14211)	30x	2x
	Particulate matter concentration	nefelometry		
	Meteorology parameters	common methods		
C	Nitrogen oxide concentration	chemiluminiscence (EN 14211)	13x	x
	Meteorology parameters	common methods		

Table 1. Classification of Air Quality ITS stations (AG ITS-S), the reference methods and the cost comparison

4.4. Air quality ITS station (AQ ITS-S)

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 particulate matter concentrations by the nephelometry method, the validation of this method must 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 1)*. 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 once a year, maintenance – regular annual service) the price rises from a less equipped station (class C) to a full-equipped station (class A).

Table 2. Air quality index and individual limits for selected pollutants (source: CHMÚ)

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

5. 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. 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 – ČHMÚ *(see Table 2)*. 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).

6. Efficient air quality measures to tackle traffic burden

There is a lot of ways to present various measures enhancing air quality. The consensus has been found in so called PUSH and PULL measures. They are classified into four main areas:

- PUSH: *emission production* (low carbon, zero emission vehicles)
- PUSH: *traffic restriction* (parking regulation, access restriction)
- PULL: *people motivation* (value added services, alternative means of transport)
- PULL: *emission absorption* (natural and technological tools)

A. Emission production

Besides manufacturers´, EU´s or Member States´ activities leading to regulation or even quotas on zero emission vehicles, significant contribution can be made by cities.

Cities can support the transfer to low carbon economy by various measures:

– *"in-house" investments* in city fleets renovations, i.e. purchases of low carbon vehicles for public transport, city police and other municipal services like waste management;

– *green public procurement,* i.e. requirements on city suppliers to use low carbon vehicles when providing services for the city.

B. Traffic restriction

The most efficient measures are restrictive ones. They require technologies to do the necessary enforcement. They can be divided into:

– *parking regulation,* i.e. visitors´ parking management by zoning with different pricing and residential parking;

– *access regulation,* i.e. low emission zones, access restriction zones and toll charging.

C. People motivation

The traffic restriction measures shall be complemented with motivation ones to enable people to make alternative choices for their travel behaviour. They can be divided into:

– *alternative means of transport,* i.e. sharing services like carsharing; scooter sharing; bikesharing; on-demand ride services (ridesourcing/TNCs, ridesplitting, and e-Hail); ridesharing; alternative transit services (shuttles and microtransit); courier network services;

– *integrated services,* integrated mobility scheme based on information level, i.e. sharing data (city/regional mobility platform, trip planning apps) and ticketing level, i.e. single fares (public transport as a backbone for other connected alternative means of transport with common clearing centre, account based ticketing).

D. Emissions absorption

These measures provide solutions for air polluted areas to decrease the levels of local pollution. These can be divided into:

– *nature based solutions,* i.e. planting trees and expanding green areas to catch and/or filter dust particles;

– *technology based solutions,* i.e. cleaning the dust from streets, watering streets and deployment of "smart" technologies (cleantech) as air washing machines or facades with titanium dioxide layer.

The four class measures scheme represents the base for the *following city decision making process*.

Table 3 below specifies the measures that should be triggered as the actions for improving air quality when the thresholds (not EU thresholds) are overstepped. The city 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.

Scenario	Air quality level	Types of actions
Index 3: Scenario 1	Satisfactory	Plans, resident questionnaires, parking zones design with long term target air quality goals, complementary tree planting, basic scenario of street cleaning.
Index 4: Scenario 2	Acceptable	Parking zones introduction with residential parking, geofencing technologies deployment, sharing concepts deployment, significant renovations of city fleets, city logistics regulation, mobility platform, mobility fund…
Index 5: Scenario 3	Bad	Plan for toll introduction or strict parking regulation deployment, major planting of trees, smog free towers 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, major planting of trees, smog free towers deployment…

Table 3. Typology of scenarios

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 solutions 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.

It is fully up to a city government to create its own air quality policy scenarios based on the air quality scenarios regarding local feasibility of the actions. The city government 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.

7. Summary

New technologies enable cities to define and then trigger various air quality measures and actions when the air quality values defined by the city are breached. The politicians are given arguments (hard data based on long term continuous monitoring) to public consultations and initiate public debate on traffic control measures that could be functional but unpopular. Using technologies enable to launch a serious debate on air quality in European cities and discussion various measures and actions to be taken at a particular street.

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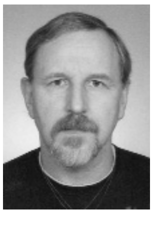

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