# The concept of a mobile air quality monitoring system for Warsaw

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In Poland and in the world is conducted air monitoring in order to care for the atmospheric air. Thus, it is possible to develop of appropriate plans of improvement air quality in certain areas. Unfortunately, the number of stationary equipment in large cities is usually insufficient. For example, in Warsaw under the State Environmental Monitoring, information on the concentrations of pollutants in the air provide only 8 automatic stations and 3 manual stations, of which only 5 stations belong to the Mazovia Voivodship Inspectorate for Environmental Protection. 11 monitoring stations in the metropolitan area of 517 $km^2$, is the number that is not able to provide an accurate measurement of air quality.
In the article, on the example of Warsaw, is presented the concept of mobile network devices for air monitoring, from which data could complement to those from the fixed stations. The article sets out the measured substances, estimated cost of mobile network devices, and the choice of means of transport to move measuring devices.
**Keywords:** air quality monitoring, sensor network, mobile sensors

## Introduction

Atmospheric air is an essential part of the environment, which is necessary for organisms living on the Earth. The clean air is composed of many gases. The most important of these include: nitrogen and oxygen, but in smaller amounts in the air are: argon, carbon dioxide, neon, helium, methane, krypton, nitrous oxide, hydrogen and xenon.

In fact, in the surrounding air exist other substances which are its impurities. Directive of the European Parliament and of the Council of 21 May 2008 [1] on ambient air quality and cleaner air for Europe defines "pollution" as any substance contained in the air, which can damage the health of people and the whole environment. Emitter of air pollutants can be both human activities (artificial source) as well as the environment.

Air pollutions have a negative impact on human health. Some substances are particularly harmful and poisonous to humans. An example of such a substance is nitrogen dioxide. It negatively affects the respiratory tract of people, can increase susceptibility to infection, pneumonia and bronchitis. It is also a cause of mutagenic and carcinogenic nitro compounds [2,3,4]. Highly toxic gas is also sulfur dioxide, which may enhance the conjunctiva and skin diseases. Negative effects on the environment is its contribution to the formation of acid rain by reaction with water vapor in the air [3,4]. Particulate matter is also harmful to human health. It can cause many respiratory diseases, including lung cancer even. Studies demonstrate compound exposure to dust from the increase in mortality of individuals suffering from pneumonia and cardiovascular problems. An example might be a fire rainforests in Indonesia in 1997, which resulted in a significant increase in the number of acute respiratory infections in humans [3, 4]. Another pollution poses a major threat to humans is carbon monoxide. This substance, upon entering the bloodstream, is associated with hemoglobin, so as to prevent oxygen transport by blood [2]. Ozone, as well as other components of photochemical smog, causes irritation in humans membranes of the nose, throats, and eyes. Ozone in plants causes a decrease in the efficiency of photosynthesis, restricts the ability to absorb carbon and inhibits their growth [2]. The heavy metals such as lead, cadmium, nickel and arsenic contribute to the formation of tumors in humans [5].

In order to care for atmospheric air, in Poland and worldwide, is conducted air monitoring. It is based on continuous control of air quality, assessment of its pollution, as well as the control of adherence to standards of acceptable concentrations of pollutants. Thus, the development of appropriate plans to improve air quality in specified areas is possible.

This paper presents the concept of a mobile air quality monitoring system for Warsaw. It could be an extension of the existing system of measuring stations. Section 2 describes the legal basis for air protection in Poland. The next section describes the types of currently used measurement devices, whereas section 4 – introduction to mobile systems. Section 5 contains the concept of the proposed system - determination of the measured substances, estimating the cost of equipment, as well as the choice of means of transport to move measuring devices. The last section is a summary.

## Legal basis for air protection in Poland

In Poland, for the inspection of the environment serves the State Environmental Monitoring (SEM), which aims and objectives are described in the Act of 27 April 2001 – Environmental Protection Law [6].

The main objective of the SEM is to support activities to protect the environment. This goal is achieved through informing authorities and the public about the quality of the individual elements of the environment and the ongoing changes. The SEM is responsible for the collection, processing and dissemination of environmental data. On the basis of measurements carried out in the SEM are created the evaluations and predictions of the environment. The SEM has several subsystems that deal with different elements of the environment, eg. air monitoring, noise monitoring, etc. Within the SEM studies leads Inspectorate for Environmental Protection, which consists of the Chief Inspectorate for Environmental Protection (CIEP) and 16 voivodship inspectorates for environmental protection (VIEP). CIEP is the coordinator of the Environmental Protection Inspectorate [6].

In the SEM within the air monitoring activities are carried out tasks, which are conditioned by the requirements of the European Parliament and the Council, and the standards of the Polish legislation on air quality. Legislation lays down important issues such as: acceptable concentrations of the pollutants in the air, target levels of pollutant concentrations and deadlines for achieving them. The statutes also contain indications on how to conduct the assessment of air quality, information on air protection programs and short-term actions.

The European Union imposed on Poland by a number of regulations, which are contained, inter alia, in the following directives:

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe,

Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, nickel, mercury and polycyclic aromatic hydrocarbons in ambient air.

Directives specify definitions, responsibilities and targets for air quality. Require Member States to draw up a European Union air quality assessments, approval of measurement systems, perform correct measurements, analysis, assessment methods and cooperation with other Member States and the Commission.

Transposition of the requirements of EU directives into national law is primarily the Act of 27 April 2001 - Environmental Protection Law (with amendments). In Poland, it is the most important document, which regulates the protection and air quality requirements. This law has a number of implementing acts:

Regulation of the Minister of Environment of 13 September 2012 on the making of the assessment levels in the air [7]. The Act defines the scope of the evaluation methods and levels of substances in the air, measurement requirements and criteria for location of pollutants measurement points.

Regulation of the Minister of Environment of 24 August 2012 on the levels of certain substances in the air [8]. This Act includes exposure limits in air pollutants such as benzene, nitrogen dioxide, nitrogen oxides, sulfur dioxide, lead, particulate matter PM2.5, particulate matter PM10, carbon monoxide.

Regulation of the Minister of Environment of 10 September 2012 on the scope and method of communicating information on air pollution [9]. This document relates to a method of informing the Chief Inspector of Environmental Protection about the classification results of zones and the results of measurements of air pollution, as well as the alarm levels exceeded.

Regulation of the Minister of Environment of 2 August 2012 on the zones, in which is evaluated air quality [10]. It contains the definition of the zone and specifies the names and codes zones in Poland.

Regulation of the Minister of Environment of 11 September 2012 on the air protection programs and short-term action plans [11]. The regulation sets out detailed requirements to be met by air protection programs.

## Classic air quality monitoring stations

In Poland, traditionally used air quality monitoring equipment are stationary measuring stations, which can be divided into: automatic, manual and passive. With these devices are made stationary measurements which concern to small regions located around the stations. Their functioning allows to obtain only the general quality of the air. For example, in Warsaw, information on the concentrations of pollutants in the air under the State Environmental Monitoring provide only 8 automatic and 3 manual stations (5 – Mazovia VIEP, 3 - PGNiG Termika, 3 - scientific institutions). Their locations are determined to obtain various types of data from the environment and are available on the websites of the VIEPs.

11 monitoring stations in the Warsaw metropolitan area of 517 km$^2$, is the number that is not able to provide an accurate measurement of the air quality. Theoretically, one station covers an area of about 47 km$^2$. However, the reality is different, because the distribution of monitoring stations in Warsaw is uneven. Some monitoring stations, eg. at Marszałkowska street and Niepodległości street are very close to each other and collect data from the same area. However, the state of air in areas remote from the monitoring station is determined by modeling on the basis of the results of measurements from stationary stations.

Automatic measurement stations use automated analyzers, which allow for continuous measurement of the concentrations of air pollutants. The devices can automatically collect and analyze samples. Measurement methods are dependent on the established reference methods measured pollutants contained in the relevant regulations, eg. the level of sulfur dioxide is measured by ultraviolet fluorescence, and the level of nitrogen dioxide by chemiluminescence. In Warsaw, by using the automatic measuring stations are measured pollutants such as: sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, methane, particulate matter and nitrogen oxides.

In the manual measuring station, to air sampling is used aspirator transmitting a certain amount of air through the probe or absorbing certain pollution scrubber. Then, based on laboratory analysis of the probe, it may be calculated concentration of substance in the air. In Warsaw, with using manual measuring stations are investigated pollutants such as: particulate matter, benzo(a)pyrene and metals such as cadmium, nickel, arsenic and lead.

The passive method is based on collecting air samples without forced air flow through the measuring system. Pollutants getting into the probe by diffusion or permeation. Next, they are retained by the absorbing agent. After a certain time, pollution probes are analyzed. This allows the calculation of air pollutant concentrations [12]. In Warsaw, there are no passive measurement stations, of which results are included in the State Environmental Monitoring reports.

## Mobile systems for air quality monitoring

Air quality can also be monitored during the movement of the measuring device on any given route. This possibility provides mobile systems for exploring air quality. This method allows for more accurate opportunity to examine air pollutions, because the measurements do not have to be carried out at fixed locations, such as in the case of stationary stations. This technique is relatively new in the world, therefore it is still being developed. Mobile air monitoring systems are of interest to the academic and commercial industry due to a number of promising benefits and features.

An example of an existing sensor network is BusNet in Sri Lanka. The network consists of sensor nodes equipped with Crossbow MICAZ GPS modules and sensors recording air pollution mounted on buses. These data, together with location coordinates obtained using GPS, are transmitted to the access point. The exchange of data occurs only when a sensor node is in range of access node [13].

Another example of a mobile sensor network is system MESSAGE (Mobile Environmental Sensing System Across Grid Environments) implemented in London. Mobile sensor nodes have been installed on public transport vehicles, private cars and bikes. In the system is monitored concentration of pollutants such as carbon monoxide and nitrogen dioxide. MESSAGE also collect data on air temperature, humidity and noise. Another sources of data on the network are stationary air monitoring stations, as well as low-cost platform sensor – Smartdust [13].

Since the technique of building network using mobile devices is relatively new, there are many issues and problems that need to be considered in their design. In the case of mobile equipment mounted on the means of public transport, there is a problem of determining the number of devices needed to cover the desired area of the city, while ensuring appropriate frequency of measurements. The analysis of such problems on the example of the tram network in Zurich is shown in [14]. The authors solved these problems with an evolutionary algorithm since computing the optimal solution is only feasible for very small transport networks. Creating a mobile network is usually associated with a greater number of sensors. In such cases are often used low-cost devices. Mead et al. [15] present results of linkages and interactions with each other low-cost sensors depending on the presence of different substances (e.g. between NO and $NO_2$ where a cross interference of 1.2% is seen). They state that the examined devices have the potential to provide a far more complete assessment of the high-granularity air quality structure generally observed in the urban environment, and could ultimately be used for quantification of human exposure as well as for monitoring and legislative purposes.

To collect information from the sensors, as well as to manage network measurement devices, are applied various concepts, technologies and standards. One of these concepts is the Sensor Web [16]. Description of the standard can be found in [17]. The main idea of Sensor Web is to build a geospatial information infrastructure, that connects the heterogeneous in situ sensors and remote sensors over the wired or wireless networks with providing: interoperability, intelligence, low cost, scalability, reliability and high resolution. [17] also includes an example of using this standard - GeoSWIFT Sensing Services, which integrates sensors from webcams. Stasch et al. [18] present a case study of providing "on-demand" aggregated data on air quality using the Sensor Web.

Examples of other standards and norms, among others: ISO/IEC 18000 (International Organization for Standardization/International Electrotechnical Commission), ISO/IEC 24753, IEEE 1451 (Institute of Electrical and Electronics Engineers), OGC SWE (Open Geospatial Consortium Sensor Web Enablement), SOS (Sensor Observation Service), SAS (Sensor Alert Service), concerning sensor networks can be found in [19]. In order to better describing the data and the ability to transforming them are created ontologies. An example is the SSN (Semantic Sensor Network) ontology developed by the W3C Semantic Sensor Network Incubator, used to describe the sensors in terms of their characteristics, measurement processes, usages and observations [20].

Mobile measuring networks are used in different places, not only in the centers of large cities. Chao-Tung et al. [21] present an example of a system for monitoring air quality in hospitals. The proposed system measures the temperature, humidity and $CO_2$ concentration. In the case of exceeding the permissible values, it sends warnings.

Currently, there is no mobile air monitoring system in Poland. In 2008, employees of Gdansk University of Technology together with the Foundation ARMAAG created a prototype mobile device (ARPOL) for measurements of gaseous pollutants. ARPOL was a device with dimensions of 25 cm x 25 cm x 12 cm. The device has been manufactured using a microcontroller with built-in analog-to-digital converters, GSM/GPRS modem, GPS receiver and RS232 serial interface. The device has offered possibility of measurements the following substances: benzene, nitrogen dioxide, nitrogen oxides, carbon monoxide and carbon dioxide. The device was tested on Tri-City roads, but its wider use has not been begun after a test phase [22,23,24].

A small number of measurement devices used for measuring air quality in Warsaw, a large area occupied by the city means that it becomes necessary to extend the existing infrastructure with new devices. It can be used for this purpose mobile systems, that are able to provide measurements over a larger area.

## The concept of a mobile air quality monitoring system for Warsaw

### Measured pollutions

Traffic pollutions are the main problem concerning air quality in Warsaw. These impurities result from a highly developed roads. According to data from the Central Statistical Office 2011, traffic pollutions are the source of over 33% of the total emissions of nitrogen oxides, over 23% of carbon monoxide and more than 20% of particulates in Poland [25]. In large cities such as Warsaw, the share of road transport in total emissions is even greater. In 2012, in the city were as many as 1 216 666 vehicles registered [25]. For this reason, monitoring should include substances that are emitted by road transport: carbon monoxide (CO), nitrogen oxides ($NO_x$), sulfur oxides ($SO_x$), particulate matter PM10.

These contaminants are a threat to human health, and the inhabitants of the city are more likely to respiratory and cardiovascular diseases due to high concentration of pollutions in air. As shown by the study, living on busy streets triples the risk of bronchial constriction, which can lead to chronic obstructive pulmonary disease (COPD) [26]. Traffic pollutions affect the formation of smog, acidify the environment and contribute to the greenhouse effect.

In addition, together with data on the amount of pollutants concentration in the air, devices should collect the data defining the conditions under which the measurements were made, such as temperature and humidity, because of correlation between weather conditions and concentration of substances [27]. For each measurement should also be attributed the time and location of its accomplishing.

Another aspect is the need to provide a standardized method for making measurements. All devices should take measurements of the same parameters in the same precise manner. A description of the conducted measurement should be logical and understandable by its standardization. It is necessary as to permit the integration of data from different devices. This will enable faster data processing, as well as their ability to obtain and exchange. Examples of standards for use with measuring devices and the observations are SensorML[1] and Observations & Measurements Schema (O&M)[2] [19,28].

SensorML is an XML scheme used to describe a model of functioning of sensors and measurement processes connected with them. With the use of SensorML, one can describe a wide range of sensors, both mobile and stationary ones, those taking measurements on site or remotely. In addition, it allows to describe algorithms needed to control sensors, localise observations made with sensors, and process them at a low level. The language is a component created by OGC as part of the specification Sensor Web Enablement (SWE) and the system Sensor Web [17].

O&M is an international standard which defines a conceptual schema encoding for observations and measurements, and for features involved in sampling when making observations. While the O&M standard was developed in the context of geographic information, it is not limited to spatial data. XML encoding in O&M is very general since the result of observations or measurements may be "packed" in any structure described in the XML format. O&M is one of the core standards in OGC.

### The system architecture and the cost of devices

To create a mobile system of air quality, it can be used ready-measuring devices or it can be designed and built specialized.

The use of ready-measuring equipment is quite difficult, because the professional devices are very expensive (from tens of thousands to hundreds of thousands of euros for a single unit). Slightly less professional devices are often created for specific needs and it is difficult to find those that meet the desired criteria.

The second possibility is interesting, because on the market are available many sensors that allow the measurement of the specific substances concentration. Their task is to convert physical quantities: temperature, relative humidity, the concentration of a substances to digital values. These systems are so-called integrated sensors, which are characterized by a high degree of integration and standardization of processing systems. In addition, they have a digital measurement interface.

[1] http://www.opengeospatial.org/standards/sensorml
[2] http://www.opengeospatial.org/standards/om

To create an independent measuring device using the described sensors, it is necessary to add to them the data collection unit responsible for reading the signals from the sensors. An essential element of such a measuring device is also a GPS receiver. This unit provides the location of the measuring device. As the last element can be a simple microprocessor system (eg. Raspberry Pi), which would control the work of the whole system, and would send the relevant data via GSM card to a central server.

In professional, but also very expensive equipment, measuring the concentration of substances in the air is performed mainly by high resolution analytical methods based on gas chromatography and mass spectrometry (eg. determination of heavy metals). These methods are characterized by a very low measurement uncertainty and high resolution, no less have a number of very significant limitations, such as:

- the need to be handled by specialized personnel (during the measurement and analysis of the results),
- long measurement time (at tens of minutes),
- difficulty in automating the measurement process,
- the need for frequent calibration of measuring equipment (in extreme cases, before each measurement).

The mobile measuring devices for measuring air parameters can use chemical sensors. The results of the measurements obtained with this type of sensors have reduced accuracy compared to professional equipment (detailed analysis about quality of electrochemical sensors can be found in [15]). Nevertheless, the parameters (eg. accuracy) of chemical sensors currently available on the market make them suitable for urban air quality measurements [15]. Approximate costs of the individual components are as follows:

- temperature – price approx. 50 PLN [3],
- humidity – price approx. 100 PLN [4],
- atmospheric pressure – price approx. 50 PLN [5],
- oxides of nitrogen – price approx. 100 PLN[6],
- sulfur oxides – price approx. 100 PLN[7],
- carbon monoxide – price approx. 50 PLN[8],
- particulate matter PM10 – price about 1100 PLN[9].

To these costs must be added the cost of the GPS receiver (approx. 120 PLN), GSM/GPRS card (approx. 150 PLN) and a microcomputer (eg. Raspberry Pi approx. 150 PLN). After taking into account additional components (eg. housing) total cost is expected to reach approx. 2000 PLN. It is worth noting, that the largest component of the total is the cost of sensor which enables measurements of PM10 concentrations. Without it, the cost of the device would be approx. 1000 PLN.

## Choice of transport platform

The set of substances selected for measuring, including particulate matter PM10 and meteorological parameters, makes that the device performing the measurements can have bigger dimensions (caused mainly by the dimensions of the sensors PM10). This property and the need to ensure the mobility of devices affect the necessity of choosing the right vehicle in which the measuring device can be installed. In Warsaw, over 60% of trips are made by public transport [29]. Therefore it is possible to use several modes of transportation that in carrying out its essential tasks could be mobile transport platforms.

The first possible transport platform are buses, which are the most popular means of transport in Warsaw. Their share is almost 35% of the total number of trips. Warsaw bus network is very dense and extensive. There are more than 200 day lines and more than 40 night lines, which are handled by approx. 1700 buses from five carriers. This is certainly an advantage, because it would be possible to obtain a vast amount of data collected along many streets in Warsaw.

Buses in the capital run around the clock. This fact would allow for continuous carrying of measurements. There are also situations when buses stand in traffic jams. In this case, measurements would be performed for a certain time in one place. Data obtained in this way would concern the amount of pollutants concentration in a variety of situations. However, buses have the defect, which consists of emissions to air significant amounts of harmful exhaust emissions, which may interfere with the devices [29].

Another potential mode of transport are taxis. In Warsaw, there are about 10,000 taxis[10]. This huge number of vehicles would allow to obtain much data. Their disadvantage is the lack of regular driving and lack of fixed and repetitive routes, which will definitely hamper the mapping of pollution. Another disadvantages are large emissions, which could affect the abnormal results of air monitoring, as well as problems with the equipment installation on vehicles.

The last possible modes of transport are trams, which in Warsaw run over 760 vehicles. It is the second most common mean of transport chosen by the inhabitants of

[3] http://botland.com.pl/czujniki-temperatury/2637-czujnik-temperatury-i-wilgotnosci-dht22-am2023-modul-przewody.html
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[5] http://botland.com.pl/szukaj?controller=search&orderby=position&orderway=desc&search_query=barometr&submit_search=
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[7] http://www.conrad.pl/Czujnik-gazu,-Figaro-TGS-822,-wykrywa-CO2%2Famoniak%2Fdwutlenek-siarki%2Falkohol%2Fbenzyne.htm?websale8=conrad&pi=183466
[8] http://botland.com.pl/czujniki-gazu/3029-czujnik-tlenku-wegla-i-latwopalnych-gazow-mq-9-modul-niebieski.html
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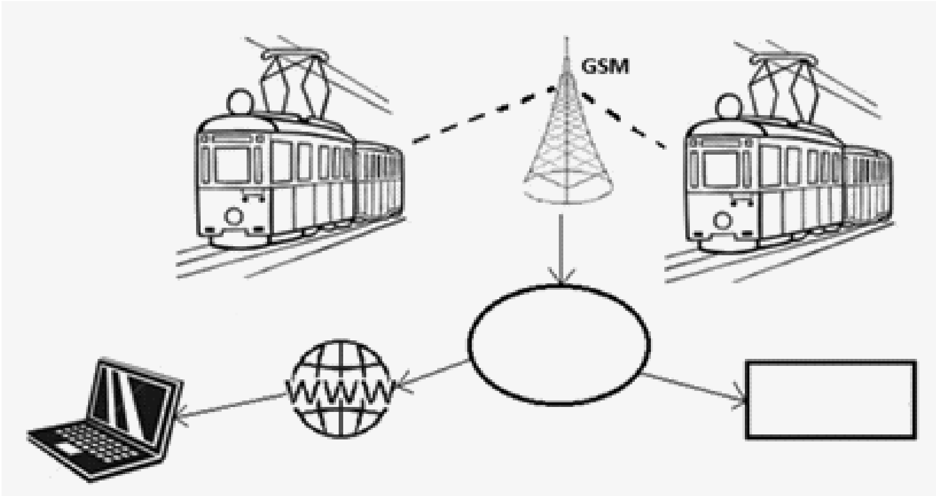


Figure 1.

Warsaw. Their share is almost 15% of all trips. Their choice as a transport platform has many advantages. Firstly, trams have constant access to a power supply, which could be also used by the measurement devices. Secondly, the devices may be mounted on the roof of trams without breaking the overall appearance of the vehicles. Thus, it would be adequately protected against theft, and easily accessible for maintenance and calibration. It is also important that the trams themselves do not emit too much pollutions. These advantages make the trams the best platform of mobile measurement devices, so they will be selected for further consideration. The disadvantage of choosing trams is that in Warsaw trams do not run at night, so there will be no possibility to make measurements around the clock. Another downside is the limited number of routes, by which move trams [29].

After installing the measuring device on the roof of the vehicle, the measurements could be carried out continuously throughout the journey of a moving vehicle with such frequency, which would be allowed for the used sensors (Fig. 1). The proposed mobile wireless sensor network should be "on-line", so that the collected data will be placed immediately to the central server using the GSM module. Another potential option is a "off-line" network, in which the measurement data would be collected by the measuring device and sent with the WiFi only when the tram would be placed near a stationary device data (eg. after returning to the depot or near the point where it would be installed a relay device). The second option would be cheaper, but the drawback would be a delay in the transmission of information and in the possibility of making it available to the public. This disadvantage would therefore be disproportionately large compared to the reduction of the cost of a single device.

Now let's try to estimate the number of necessary devices depending on the variant of the measurements. In the first scenario we assume that the vehicles from one line will be equipped with measuring devices, in the second scenario - that a greater number of vehicles will be equipped with a measuring devices so that the measurements should be carried out in each region of the city where trams go.

### Using a single tram line

In the first example, we assumed that proposed system would include one tram line in Warsaw. For this purpose, it was selected line number 24 shuttling from Gocławek to Nowe Bemowo, with a length of about 20 kilometers. The line has a fairly diverse route for transportation. It goes along the streets with high traffic, as well as through the center of the city, where often form the congestions. Trams 24 also go near Park Skaryszewski, which is a large green area, next to the airport in Bemowo and the areas away from the city center, which is the most polluted. This route pretty well represents a diverse characteristics of the city and the associated possible different concentrations of pollutants in the air.

Number of trams measurement devices should be large enough to accurately depict the changes in air quality.

As at the beginning of January 2015, trams 24 run every day from 04:30 to 00:00[11]. On weekdays, during rush hour run every 5 minutes, and between the rush hours – every 7-8 minutes. Trams travel the route in one direction for about one hour. In order to provide the desired frequency of measurements, trams with mounted equipment should leave the tram terminus Nowe Bemowo at rush hours every 5 minutes (in accordance with the available timetable), and the measurements should be carried out in both directions of trams movement. It was assumed that vehicles stay 5 minutes on the tram terminus. This means that it takes a minimum of 24 trams with mounted equipment to ensure a measurement in a given place at least once every five minutes during rush hours. Measurements should be performed at a frequency of once a minute (getting more frequent measurements may be difficult due to

Table 1. Tram lines

| Number of tram line | Interval in [min] between adjacent departures | Travel time [min] in one way | The minimum number of required devices |
|---|---|---|---|
| 1 | 5 | 51 | 13 |
| 2 | 6 | 15 | 5 |
| 3 | 10 | 43 | 11 |
| 15 | 10 | 54 | 13 |
| 17 | 5 | 64 | 15 |
| 20 | 10 | 55 | 13 |
| 24 | 5 | 63 | 15 |
| 26 | 5 | 55 | 13 |
| 33 | 5 | 48 | 12 |
| 35 | 10 | 67 | 16 |

the construction and operation of the sensors). The cost of these devices (without additional costs, eg. installation on trams, server for collecting data, backup devices, etc.) would amount 48,000 PLN (= 24 devices * 2000 pln).

In the off-peak hours, on Saturdays and public holidays due to the smaller number of riding vehicles, the frequency of measurements will be obviously smaller (smaller number of trams in motion means rare passing at a given point and thus less frequent measurements).

**Using the tram network**

The next simulation assumes the use of a larger number of tram routes, so that the measurements should be performed in each district where are tram lines. For this purpose, devices can be installed on trams the go each lines or it can be selected a subset of lines that cover all routes. As an example of the second case, the following lines are typed: 1, 2, 3, 15, 17, 20, 24, 26, 33, 35 (of course, there are many combinations of lines that cover all routes). Due to the differentiated frequency of running trams of particular lines and overlap routes in the central areas of cities, it is assumed that vehicles with a measuring devices should depart out of the terminus at about 10 min., and the trams stop on the terminus approx. 10 min.

Table 1 presents data on particular tram lines (as at the beginning of January 2015, refers to the rush hours, source: www.ztm.waw.pl).

The above table shows that a fairly good coverage tram routes with measurements need 126 devices. Their cost (without additional costs, eg. installation on trams, server for collecting data, backup devices, etc.) would amount to 252,000 PLN (= 126 devices * 2000 pln).

## Summary

The creation of mobile air quality monitoring system would certainly be a good complement to the current network of stationary stations and would improve air quality measurements. The resulting data could be added to the reports made under the State Environmental Monitoring or could be the basis of the various analyzes, eg. changes in the concentration of nitrogen dioxide in different places in Warsaw.

Introduction of the mobile air monitoring system in the Warsaw agglomeration area could bring many other benefits. This could result in increased human interest in problem of air pollution in cities. Each person could have access to the results of the measurements. Paying attention the inhabitants to the poor state of the air in Warsaw may also affect their conscious choice of means of transport, eg. resignation of travel by car and choosing bicycle or public transport. Such behavior in a significant number of inhabitants can contribute, among others, to reduce the concentration of nitrogen dioxide, which main sources are the emissions from motor vehicles.

Implementation of the system and use of the results could be also interested in public administration managing health and transport policy of cities (eg. as a complement to the existing monitoring system), as well as business (eg. offering health insurances and life insurances) scientific and research institutions dealing with issues of air quality and related topics.

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