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A new approach to link transport emissions and air quality: An intelligent transport system based on the control of traffic air pollution

F. Costabile*, I. Allegrini

Institute for Atmospheric Pollution, National Research Council (CNR-IIA), Via Salaria Km 29, 300, C.P. 10 Monterotondo Stazione, Rome, Italy

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Abstract

Road transport has become by far the major source of environmental pollution and traffic congestion in urban areas. Though a lot of research has been done to investigate the functional relationship linking air quality and air pollution from transport, a further improvement in the knowing of this relationship is needed. The aim of this study was to analyze this relationship and to develop a more flexible framework to allow communication between transport emissions and air quality concentrations. This paper describes the development of this framework, suggests methodological tools to mitigate its problems and shows its application to the mega-city of Beijing, in P.R. China. The result of implementing this methodology would be a system providing high time/space resolution measurements of both air pollutant concentrations and traffic emissions data, as well as real-time transportation and dispersion modelling of those data. The key advantage of the system proposed would be the runtime integration of modelling, to interpret the data measured, with measurements, to validate the data modelled. The findings from the case-study of Beijing show that the integrated system can link traffic air pollution measurements through various modelling modules in order to automate transport-related air pollution assessment.
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Keywords: Air pollution; Traffic; Emissions; Concentrations; Modelling; Measurements

1. Introduction

Road transport has become by far the major source of environmental pollution and traffic congestion in urban areas. The continual traffic growth has raised concerns over the impact of traffic emissions on human health and urban environmental quality, and has fuelled the demand for a coherent regulatory framework for the management of traffic, air quality and emission at urban level, as well as at regional and national scales. Particularly, urban congestion and air pollution are seen as a high priority problem in China (UNEP, 1997). In Beijing air quality is in transition from coal burning caused problems to traffic exhaust related pollution (Zhang et al., 1997) since the number of private passenger cars is increasing dramatically recently and in the near future. Vehicle emissions are, therefore, projected to double within the next two decades unless drastic strategies to lower actual emissions are employed.

In the design of cost effective abatement strategies it must be realized that the relations between emissions and resulting concentrations are by no means simple. A lot of research has been done to investigate this issue. Most of the emission factors used by the emission inventories to quantify traffic contribution upon total emissions originate from laboratory measurements carried out according to specific measure and driving protocols (e.g. Hausberger et al., 2003). However, for real world application the model calculations must be based on true emission data and their estimation is not trivial. In a recent work conducted by analyzing the relationships between the Danish Operational Street Pollution Model (OSPM) predictions and concentrations measurements, Berkowicz et al. (2006) found that the application of COPERT emission factors can lead to a significant underestimation of street level pollution concentrations. On the opposite, pollutant concentrations have been measured

* Corresponding author. Tel.: +39 06 90672974; fax: +39 06 90672660.
E-mail addresses: costabile@iia.cnr.it (F. Costabile), allegrini@iia.cnr.it (I. Allegrini).

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on the road to infer emission profiles and rates (Querol et al., 2002; Shi et al., 1999): besides temperature and humidity, these results strongly depend on wind speed and direction, and, therefore, on the temporal variation of dilution rate; they account for a mix of vehicles indeed. To remove the effect of wind, measurement stations inside tunnels have been used. However, distribution profiles of not all the pollutants measured in such a way can represent ambient air conditions (Sturm et al., 2003). In order to solve these issues and also obtain results that can discriminate emitting vehicle type, whether chasing experiments on the road (e.g. Kittelson et al., 2002; Vogt et al., 2003) or simulation of exhaust dilution in ambient air (e.g. Sasaki and Nakajima, 2002; Maricq et al., 2002) have been carried out.

However, a further improvement in the knowing of this relationship is needed. Measurements are still the foundation of our understanding, but application of mathematical and physical modelling is of increasing importance in urban air pollution management (Fenger, 1999). In a recent study (Mediavilla-Sahagun and ApSimon, 2006) an Urban Scale Integrated Assessment Model (USIAM) was used to assess potential air pollution abatement strategies; source–receptor relationships were defined by means of pre-calculated dispersion matrices for investigation in terms of achieving environmental target and cost effectiveness. In another recent study (Calori et al., 2006) an integrated modelling system was used to reproduce concentration behaviours; the reproducibility was higher in "urban background" or suburban stations, and lower in sites heavily affected by nearby traffic. This was attributed to spatial resolution effects (local traffic emissions' modulation and urban boundary layer modelling) whose importance on urban sustainability and air quality have been assessed in another recent work (Borrego et al., 2006). Moreover, statistical models have recently been applied to provide with an operational air quality forecasting module (e.g. for PM_{10} Slini et al., 2006) and to evaluate the impact of traffic emissions on the statistical distributional form of air pollutant concentrations (e.g. Gokhale and Khare, 2007; Costabile et al., 2006a). They demonstrate promising operational forecasting capabilities. All those models can be further developed to form full decision support systems (e.g. Dennis et al., 1996) to be integrated with measurements (e.g. Carras et al., 2002; Schmidt and Schafer, 1998). Recent developments show a continuum between integrated assessment modelling and environmental decision support systems (EDSS) with varying levels of stakeholder participation in both EDSS development and application (Matthies et al., 2007).

This paper reports some of the results of a big project ongoing in Beijing (China) aimed at analyzing the relationship between urban traffic and air quality. The objective of this paper is to assess a new framework which allows the communication between transport emissions and air pollutant concentrations, as well as address a need of continuous research. It would also provide policy-makers with valuable lessons learned regarding transportation programs which promote economic development while reducing pollution impacts. The design of the system, the methodologies and the requirements of measurements and modelling, and the results from its feasibility study for the mega-city of Beijing are discussed; the test run still in progress should be addressed in future works.

2. Methodology: steps in the system modelling process

The inherent difficulties in validating integrated systems make necessary the use of good practice in their development (e.g. Ravetz, 1997; Parker et al., 2002; Van der Sluijs et al., 2005; Caminiti, 2004; Refsgaard et al., 2005; Jakeman et al., 2006); that is, clear statement of modelling objectives, adequate setting out of model assumptions and their implications, and reporting of system results, including validation/evaluation. It is worth stressing that the system performance may be assessed against many criteria, but often no sharp acceptance threshold exists. To solve these issues the major steps recently elucidated by Jakeman et al. (2006) were considered in the system modelling process of this work. First of all, the purposes for system modelling were defined; that is, the improvement of understanding and the analysis of the source–receptor relationship relative to traffic air pollution. The quality of management decisions should rest ultimately on how well the system is understood, and then insights should improve decisions. A crucial step was then to decide where the boundary of the modelled system was. The conceptual boundary was stated by the system objective, that is the development of a tool contributing to the reduction of greenhouse gas emissions and other pollutants generated by motor vehicles. Everything outside and not crossing these boundaries was necessarily ignored, and everything crossing the boundaries was treated as external forcing or as outputs. The third step included the definition of data, prior knowledge and assumptions about processes by means of a conceptualisation (Fig. 1) about the working of the system to be modelled (e.g. Gawthrop and Smith, 1996). Major features of the model structure such as the links between system components and processes were then specified (Fig. 2) to sharpen the conceptualisation. The next choice was of how to estimate the parameter values and supply non-parametric variables and/or data. The choice of measuring the highest number of variables and of how to put the model together took account not only of what data could be obtained, but also of its informativeness (Jakeman et al., 2006) and representativeness (Costabile et al., 2006b). The choice of methods for finding model parameters, as well as criteria and techniques, was then followed by a further step addressing the iterative process of finding the most suitable system structure. This step should ideally involve hypothesis testing of alternative structures (Jakeman et al., 2006); however, due to the complexity of interactions proposed here this process consisted of seeing whether particular parameters could be dropped or had to be added. Once identified, the system model was checked for feasibility to the real case of the mega-city of Beijing with the definition of an implementation boundary (a Low Emission Zone, Fig. 3). This step should ensure a system sufficiently insensitive to possible deviations from the idealising assumptions made. Since uncertainty is difficult to deal within such large, integrated systems, the model was finally evaluated in the light of its objectives. In effect, for simpler systems, a traditional scientific attitude can be taken towards validation; that is, confirmation is considered to be demonstrated by evaluating system performance against data not used to construct the model (Ljung, 1999: ch. 16; Soderstrom and Stoica, 1989: ch. 11). However, this level of confirmation was not possible or perhaps even appropriate (e.g. Jakeman et al., 2006) for such large, integrated system. The criteria were then fitness for purpose and transparency of the process by which the system was produced (e.g. Jakeman et al., 2006; Ravetz, 1997).

In summary, the methodology developed can be broadly divided in four stages, namely, requirement analysis, system design, system implementation, and system testing. That is detailed in the followings.

2.1. Requirement analysis

The requirement analysis was approached by step: (i) identification of environmental objectives for air quality; (ii) establishment of emission reduction targets and appropriate functional relationships with pollutant concentrations; (iii) monitoring of air quality; (iv) collection of input data related to the effects of potential measures on emission reduction; (v) (preliminary) assessments as the basis for future air quality strategies (network design). A careful

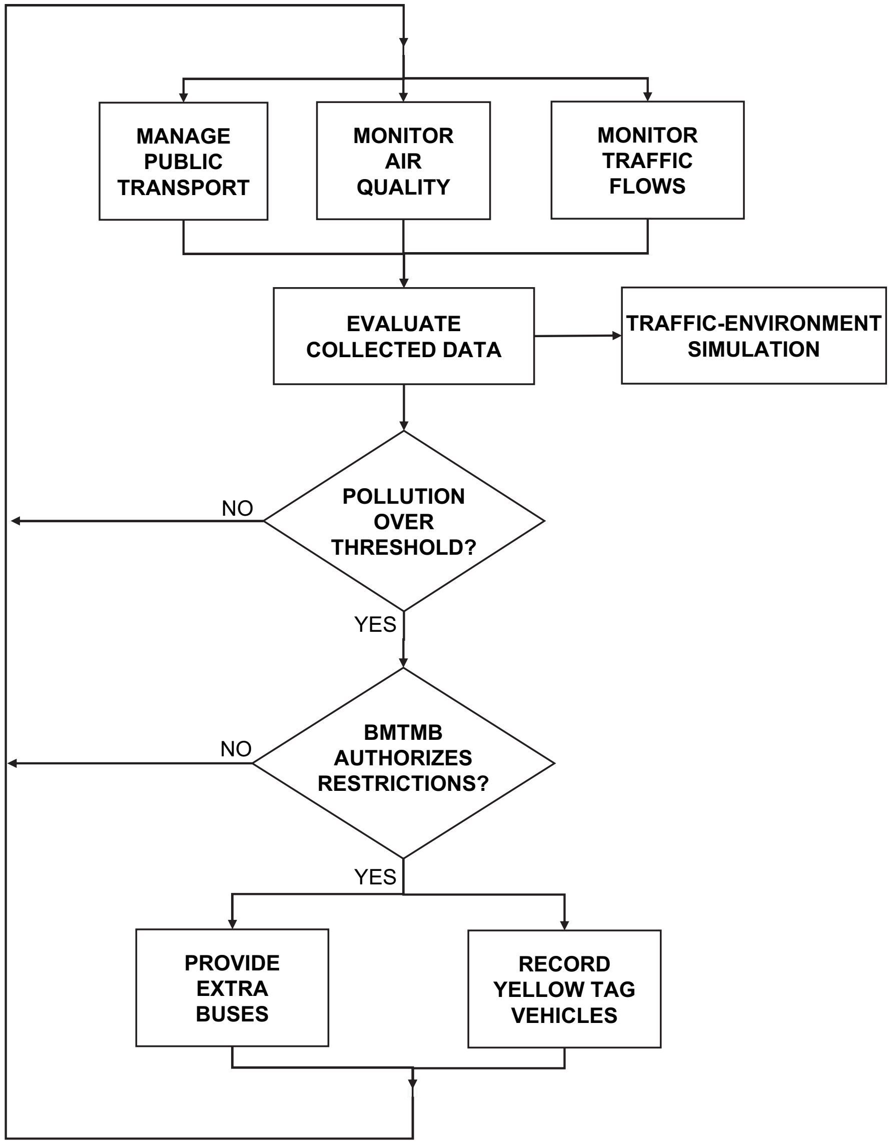

Fig. 1. Decisional diagram of the Beijing ITS-TAP project.

quantitative assessment was made to ensure that these requirements were met. It is worth stressing that because of considerable effort and insight into the processes operating in the system, it was given significant attention to such assessment to avoid that ill-chosen sampling intervals in time and space could destroy the validity of the model (Jakeman et al., 2006). The final target was the implementation of an integrated system of intelligent transport technology having as driving force a well-planned traffic air quality monitoring network. Its general objective was to develop tools contributing to the reduction of greenhouse gas emissions and other pollutants generated by motor vehicles, specifically testing and validating an innovative and integrated system of mobility management aimed at reducing the pollution generated by the traffic.

2.2. System design

The main system components are: (1) a Data Centre (DC) for the integrated management of the system which incorporates a traffic-environmental modelling tool (TEM); (2) a network of air quality monitoring stations (AQMS); (3) a network of private traffic monitoring stations (TMS); (4) a Public Transport Management Subsystem (PTMS). The modelling tool, TEM, runs air quality calculations aimed at identifying strategies and actions to manage private and public transport. The software system considers the combined use of two different kinds of simulation tools. Based on previous models (Guelat et al., 1990), the first tool (e.g. D'appolonia, 1995) seeks to solve the two typical problems of passenger intermodality in urban areas and freight transport planning at regional macro-scale; as in a typical aggregated assignment model (De Ortuzar and Willumsen, 1990) the simulation procedure implemented consists in searching all the constraint-consistent and transport-efficient routes linking each OD pair and then splitting up the OD total flow on these routes. The second tool (e.g. D'appolonia, 1997) investigates public and private road traffic relative to air pollution; it fully simulates urban traffic (also considering traffic limited zones, road tolls and area pricing, etc.), evaluates and updates the emission factors (CORINAIR, 1999) based on TMS measurements, diffuses and disperses the pollutant concentrations measured by the AQMS as a function of meteorological conditions and road geometries (e.g. canyon effect), and computes efficiency parameters at macro level (Ott, 1978). The measurement data are provided by the integration of TMS and AQMS. TMS is composed of sensors for the measurement of traffic flow (both private and public) and composition (type of vehicle, polluting labels, number of plate, etc.), as well as traffic emissions (on the road remote sensors and analysers); thus, in case of traffic restrictions TMS could identify grossly

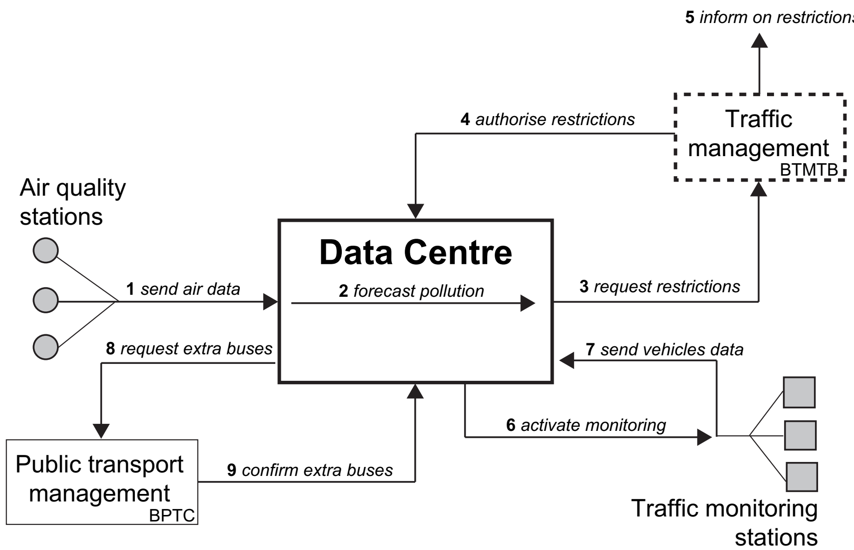

Fig. 2. Action scheme of the Beijing ITS-TAP project.

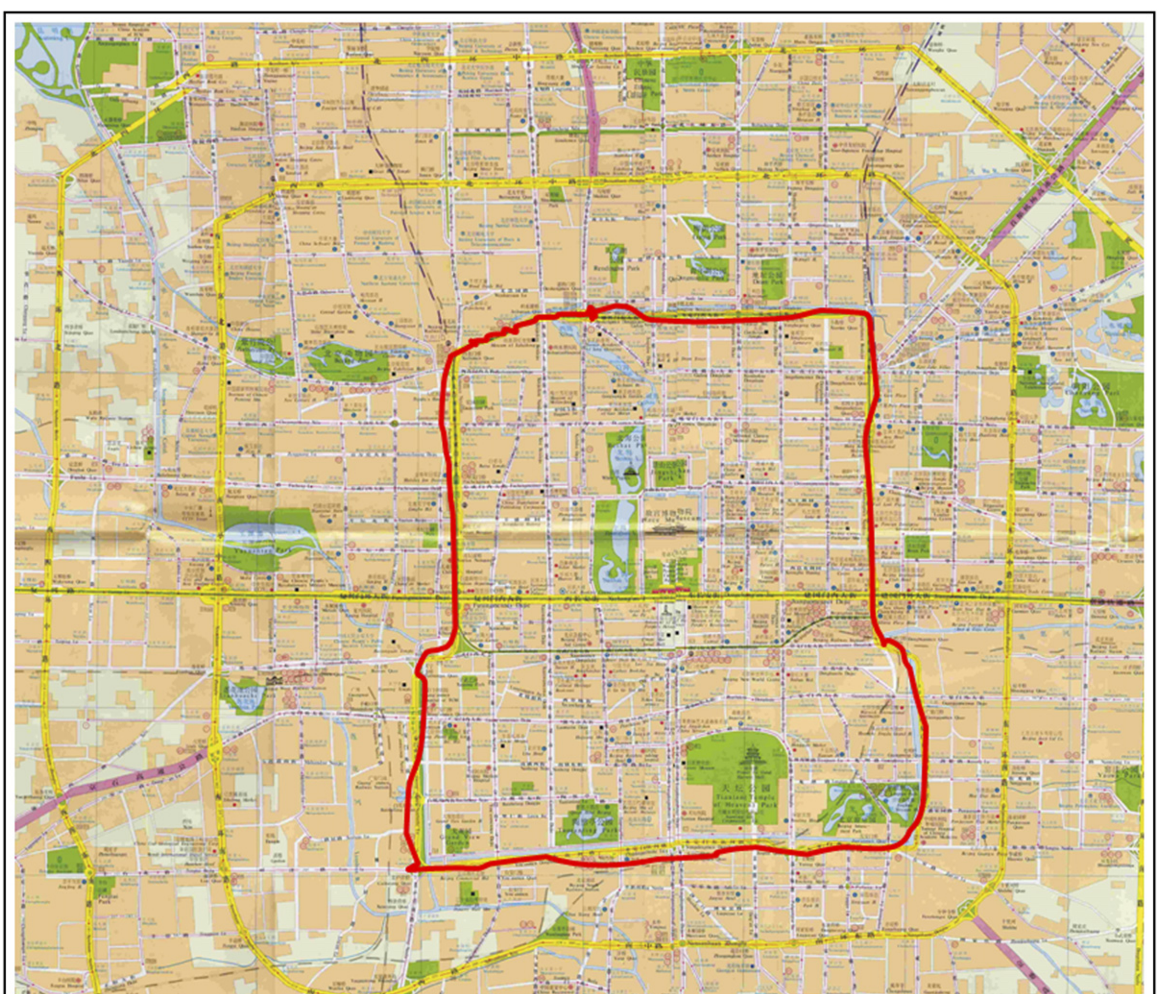

Fig. 3. Beijing's ITS-TAP. Location of the Low Emission Zone.

polluting vehicles (Costabile et al., 2004) and record the plates of vehicles entering sensible areas. The AQMS core-module measures the air pollutant concentrations to input the whole system; it is composed of monitoring stations representative of traffic air pollution equipped with automatic and manual apparatuses for the measurement of selected gaseous and particulate air pollutants and meteorological parameters (Costabile et al., 2006b). The spatial representativeness of the AQMS, requested to guarantee the reliability of air quality measurements, is mainly defined by the protocol used to select its measurement locations (network design): the sites are located in relation to known traffic sources to reflect their impact on the measurements (Costabile et al., 2006a). Finally, the PTMS seeks to optimize the public transport fleet management (optimization of operational tasks, routes and vehicles allocation, bus load optimization) and improve the service quality by sharing of information, over and above service planning and dispatching procedures, real time fleet management of public transport service (via GPS localization of buses) and real time information to the public. The four components form the basic structure of the system, but there are a number of interface modules within each component providing the link between the various air quality and transportation tools; the number of interface modules may vary between the components and a future development of the framework can easily accommodate more of them.

2.3. System implementation

The relationship between these components (Fig. 1) mainly defines the framework to link transport and air quality. The measured data of both air quality and public/private traffic flows input the TEM where the transportation model calculates the traffic-generated emissions and the dispersion model calculates the concentrations throughout the interested areas. Should the system determine pollution levels which exceed the target values, sensible areas of the city can be banned to pollutant vehicles and transformed in low emission zones where to provide extra public transportation. Therefore, the system would allow competent authorities to perform the following action scheme (Fig. 2): (1) to receive air quality data through the integration of measurements (AQMS, TMS) and modelling (TEM) tools; (2) in case of high level of pollution to ask the local authorities to authorize traffic restrictions for polluting vehicles; (3) to manage the TMS to control that polluting private vehicles do not enter the restricted areas; (4) to provide extra public transportation by the PTMS to compensate for private traffic restrictions. By keeping track of date, time and other relevant data generated every time such a scheme is activated, it would be possible to create the basis for a scientific study on the relationship between air pollution and traffic restriction countermeasures.

2.4. System testing

System testing was performed from 2003 to 2004 through a feasibility study for the mega-city of Beijing whose main outcome was the planning of an Intelligent Transport System based on the control of Traffic Air Pollution (ITS-TAP). Located in the northern part of China, Beijing has a population of 13.8 million people (end of 2001) with a growing economy and breakthrough in road construction: by the end of 2001, the total length of roads reached 4200 km (Beijing Environmental Protection Bureau, 2003). By May 2005, the number of motor vehicles exceeded 2.4 million, and it is expected to reach 3.5 million in 2008 (Chinese Academy of Science, 2006). The rapid increase in the number of motor vehicles has resulted in severe traffic jams, slow speeds, extended travel lengths and worsening of air pollution. Although the municipal government has invested more money in terms of traffic management facilities, it is still hard to satisfy the traffic demands that are growing fast; the average load of the road networks of the central urban area exceeds 90% in peak periods, the average motor vehicle speed on the urban roads is below 40 km/h, the number of intersections with vehicle flow volume of over 10 000 per hour keeps growing, and the annual increase in the average vehicle flow volume at intersections exceeds 10% (Chinese Academy of Science, 2006). To a great extent, Beijing's air quality depends on the quantity and quality of emission sources (Figs. 4–7) and has a strong seasonality (much dirtier in heating seasons due to the cold climate). Because of the limited alternative resources, coal is used as the major energy supply, causing coal-burning for heating to be the single biggest contributor to air pollution in winter. Even pollution from dust storms originating in the semi-dry area of the northern part of China is a severe problem. However, automobile exhaust emissions are becoming increasingly serious. The overall technological standards of the motor vehicles in Beijing are relatively low resulting in traffic emissions several times higher than those of developed countries; according to the results of Phase II Emission Standard executed in Beijing in 2004, the amount of the exhaust emitted by old vehicles (accounting for 10–20% of the total number of vehicles) may take up 40–50% of the total amount of exhausts emitted by all the motor vehicles (Chinese Academy of Science, 2006). In order to control traffic pollution 430 000 vehicles were labelled with green environmental protection labels, public transportation enhanced (13 000 public transit vehicles and 65 000 taxis were in operation in 2001, Fig. 8), LPG-fuelled buses increased to 4000 (Beijing EPB, 2003). However, Beijing's air quality (Table 1) is not attained to the national air quality standard (Table 2). SO_2 concentrations are still high in heating seasons (Fig. 7) even if concentrations are lowering in recent years thanks the low sulphur coal and natural gas (Fig. 9). NO_x concentrations (also higher in heating seasons) are still around 100 μg/m^3 in non-heating seasons (Fig. 10), being vehicle exhausts one of the main sources (Beijing Environmental Protection Bureau, 2003).

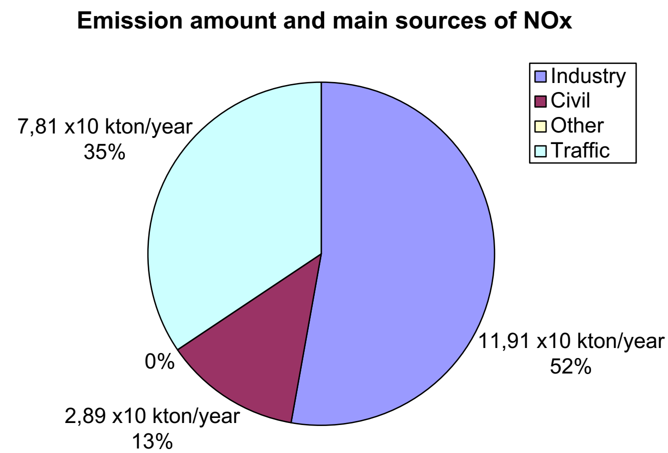

Fig. 4. Emission amount (in kton/year and percentage) and main sources of NO_x in Beijing (reference year 2001) (Beijing Environmental Protection Bureau, 2003).

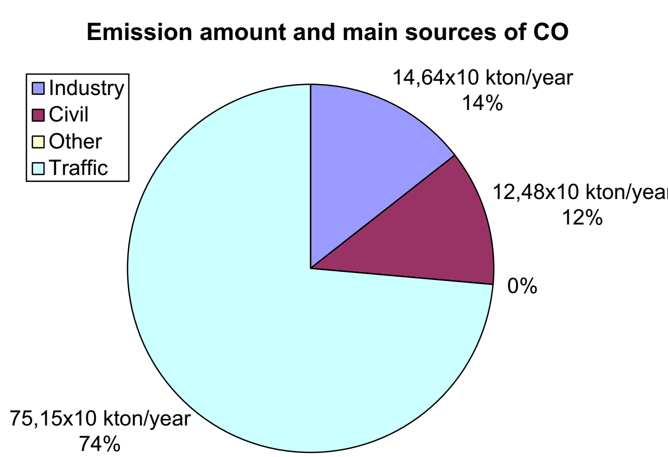

Fig. 5. Emission amount (in kton/year and percentage) and main sources of CO in Beijing (reference year 2001) (Beijing Environmental Protection Bureau, 2003).

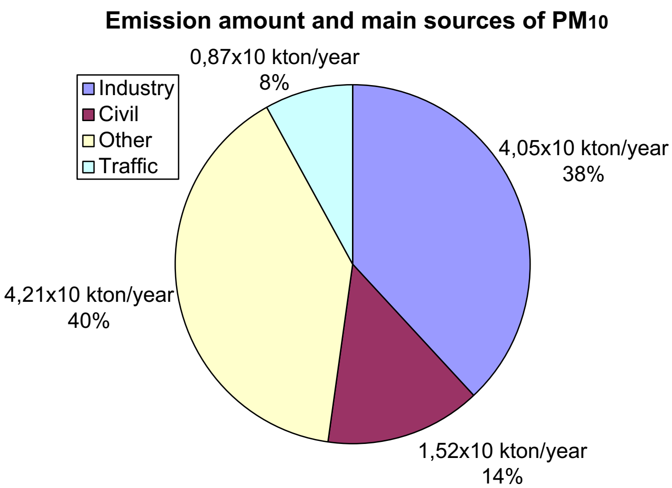

Fig. 6. Emission amount (in kton/year and percentage) and main sources of SO_2 in Beijing (reference year 2001) (Beijing Environmental Protection Bureau, 2003).

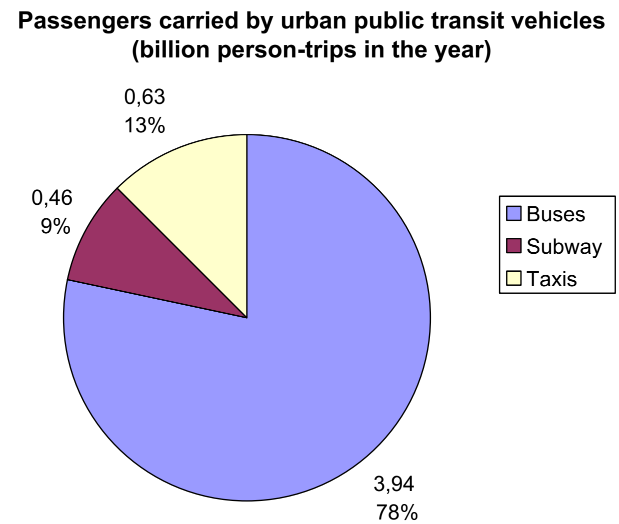

Fig. 8. Capacity of public transport in Beijing in 2001 (Beijing Environmental Protection Bureau, 2003).

3. Results and discussion

The methodology presented in this paper is based on five main operation strategies: (1) set up of a transportation and dispersion model simulating the mobility of different scenarios and calculating motor vehicle emissions and air quality; (2) measurement of pollutant concentrations in ambient air; (3) measurement of traffic-generated emissions; (4) monitoring of traffic sources; and (5) management of public transport. The final result is an integrated system, which would link traffic and air quality measurements through different modelling modules in order to automate transport-related air pollution assessment. The essentiality of each stand-alone component relative to all the others, its clear functionalities and targets, as well as the integration of measurement and modelling tools, result in the key-feature of the system. That is detailed in the following sections.

3.1. Runtime integration of modelling and measurements

In view of the complications and uncertainties remaining in the high-resolution urban air quality modelling, most of the assessments of human exposure to date have used measurements, not modelling. Software has been developed to integrate transportation and dispersion models (Lim et al., 2005); some applications have been designed for specific models (Namdeo et al., 2002) while others require considerable computing resources on a client–server architecture (Schmidt and Schafer, 1998). However, only measurements cannot solve the air pollutant concentration field of an urban environment. The system implementing the methodology presented in this paper seeks to provide high time and space resolution measurements of both air pollutant concentrations and traffic emissions, as well as real-time transportation and dispersion modelling of those data. The traffic flows measured are continuously elaborated by the transportation model to generate known linear emission sources; the emissions calculated are diffused by the dispersion model to simulate the air pollutant concentration field that is continuously compared with the real-time measurements provided by the AQMS in order to train and validate the models with a back-propagation scheme. In such a way the system would be able to foresee pollutant concentrations and analyze the concentration field with good accuracy. Thus, the key advantage of the system would be the runtime integration of measurements and modelling. Moreover, since the dispersion modelling is known to be time-consuming (e.g. Berkowicz et al., 2006) (particularly in the data preparation and analysis stages), our methodology would significantly reduce the pre- and post-processing time (especially for the model validation)

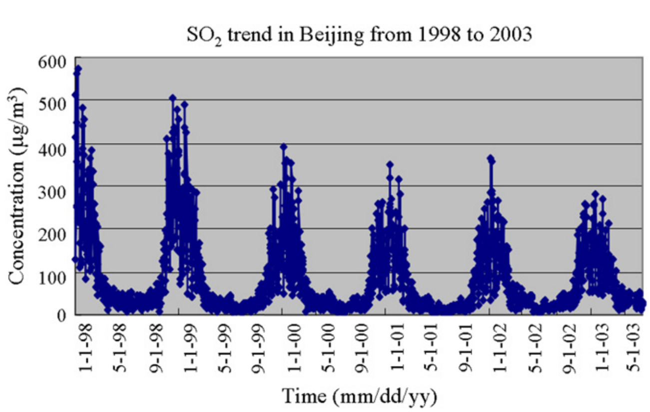

Fig. 7. Daily concentrations of SO_2 in Beijing in 1998–2003 (Beijing Environmental Protection Bureau, 2003).

Table 1
Annual daily average concentration in Beijing from 2000 to 2004 (Beijing Environmental Protection Bureau, 2003; Chinese Academy of Science, 2006)

Year	PM_{10} (μg/m^3)	NO_2 (μg/m^3)	SO_2 (μg/m^3)
2000	113	71	71
2001	115	71	64
2002	115	76	67
2003	141	72	61
2004	149	71	55

Table 2
Chinese standard and EU limits for pollutant concentrations in urban areas

Pollutant	Period	European limit	Chinese standard (Level II)
SO_2 (μg/m^3)	Year average	20	60
	Day average	125	150
	1 h average	350	500
TSP (μg/m^3)	Year average		200
	Day average		300
PM_{10} (μg/m^3)	Year average	40	100
	Day average	50	150
NO_2 (μg/m^3)	Year average	50	
	Day average		120
	1 h average	250	
CO (μg/m^3)	Day average		4
	Max. upon mobile mean of 8 h	10	
	1 h average		10
O_3 (μg/m^3)	Max. upon mobile mean of 8 h	120	
	1 h average		160
Pb (μg/m^3)	Season		1,5
	Year average	0,5	1

by the integration with the measurements. Different traffic scenarios can be quickly evaluated to screen out those that may be unfeasible; conversely, beneficial scenarios can be identified and then fully tested using whether air pollution or congestion targets, or rather a combination of them.

3.2. Measurement of pollutant concentrations in ambient air

The simplest approach to input the model is to use air pollutant concentration data measured by a single city-centre or suburban background air quality station as a surrogate for the daily level of air pollution to which the whole population of a city is exposed. However, each urban areas is characterised by several air pollution exposure zones: urban background, traffic, industrial, residential, regional background, etc. (European Commission, 1998); thus, at least one

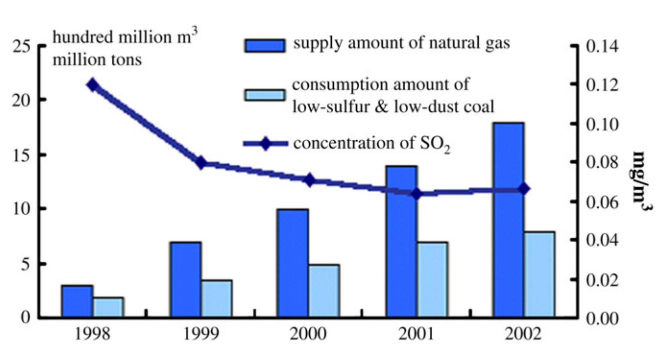

Fig. 9. Average year SO_2 concentrations in Beijing (1998–2002) (Beijing Environmental Protection Bureau, 2003).

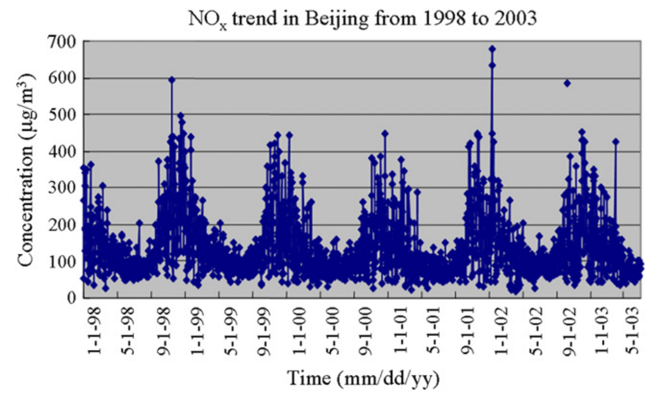

Fig. 10. Daily concentrations of NO_2 in Beijing in 1998–2003 (Beijing Environmental Protection Bureau, 2003).

monitoring station representative of each of the above-mentioned zones must be included in the AQMS module (e.g. Costabile et al., 2006b). Furthermore, besides emissions and meteorology the air pollutant concentration field of each exposure zone depends on its particular urban topography and morphology, and relative atmospheric chemistry; thus, more measurement points should be selected in each exposure zone. It is worth to mention that an accurate assessment cannot consider all the monitored pollutants at the same time, but a different analysis should be performed for each pollutant; thus, the simple approach above stated will be more accurate for a pollutant such as PM_{10} that has major distant sources than for a pollutant such as CO or NO_x predominantly emitted by the local road transport (Colvile et al., 2001). As an example, NO_x are produced during the combustion processes at high temperature for oxidation of the nitrogen in air and in the fuel and the first by-product is NO (primary pollutant), while NO_2 can be formed only when the oxygen is enough to let the further oxidation of NO to NO_2 (secondary pollutant); thus, high NO_2 emissions can be measured in urban areas only in processes involving high excess of air (low load diesel engines) or areas far from the primary sources of NO. Our system seeks to address such micro-design criteria including

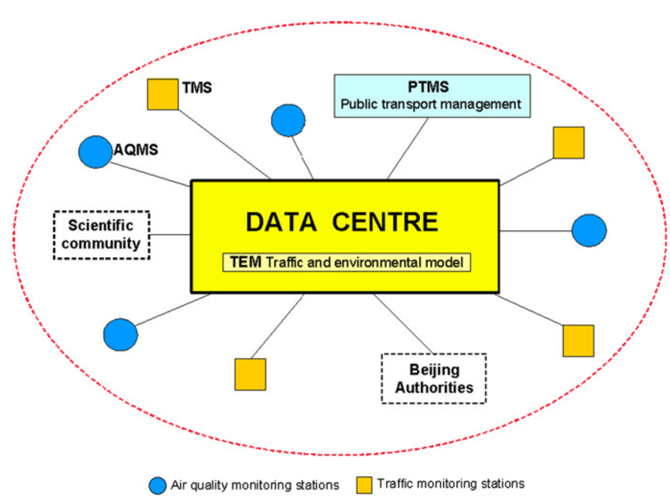

Fig. 11. Configuration and action scheme of ITS-TAP project in Beijing.

more monitoring stations differently equipped for the measurement of different pollutants to be representative of different zones. Therefore, the scope of the AQMS relative to the whole system would be to correctly provide the measurement tools necessary to solve these issues, assuming consequently the impossibility to obtain any sort of concentration field as provided by the dispersion model without using a well-designed, dense and representative network of pollutant concentration measurements indeed.

3.3. Measurements on the road of traffic emissions and sources

Road transport is distinguished from other sources of air pollution in that the emissions are released in very close proximity to human receptors (Colvile et al., 2001). This reduces the opportunity for the atmosphere to dilute the emissions which would render them less likely to damage human health. Furthermore, in most city centre atmospheres, the vehicle exhaust concentrations are significantly enhanced by the fact that many roads have buildings alongside; the effect of such buildings is to shelter the road reducing the wind speed at the source of emissions by as much as an order of magnitude relative to that on an open road (e.g. Costabile et al., 2006c). The contribution of emissions from traffic on that road to the kerbside pollutant concentrations is increased by approximately the same factor. Thus, it seems necessary to monitor on the road by the TMS the pollutant emissions to be compared with the pollutant concentrations measured by the AQMS. Despite the very large uncertainties in all evaluations of air quality impacts, the traffic source monitoring is an essential item of such kind of systems since, as before said, the pollutant concentrations from road traffic sources tend to exhibit much more spatial variability than those from non-road networks. Reliable data on total traffic emissions are crucial for the calculated street level concentrations, and even more the right proportion of traffic emissions attributed to different vehicle categories (e.g. Berkowicz et al., 2006). Therefore, one of the main outcome of the integrated system here discussed is its suitability to give detailed information about traffic emissions and sources to determine which combination of fuel type, engine type and end-of-pipe emissions abatement technology is likely to be most effective at reducing impacts on human health (Colvile et al., 2001); that is, in fact, the main target of the TMS module.

3.4. Results from the Beijing ITS-TAP feasibility study and system design

The methodology here discussed was used to perform the feasibility study, system design and planning of the Beijing ITS-TAP project, whose general configuration is shown in Fig. 11. Among the main results of this work are some transportation structure forecasts and initial policy measures. First of all, a Low Emission Zone (LEZ) where to run the ITS-TAP was planned in Beijing, assuming that the project cannot be implemented in all the cities, but like any other planning a system boundary is needed to be defined (Yang, 1998). The LEZ will be established in the urban centre area (the so-called ‘‘Second Ring Road’’, Fig. 3). Nineteen sets of vehicle type and flow measurement facilities will be set-up on the main traffic trunk roads entering the LEZ (Fig. 12). In view of the system running during the 2008-Olympic Games, three further sets will be established on Xueyuan Road (Xizhimen–Qinghenanqiao Bridge, the narrow vertical strap area on the central top of Figs. 12 and 3) that is the backbone road connecting the LEZ to the Olympic Village, expected to be mainly impacted from traffic in that period. Then, the policy measures suggested on the basis of the ITS-TAP feasibility study in Beijing include: (1) focus on public transport development; (2) management of private passenger car traffic on the basis of air pollution; (3) imposition of high penalties on those vehicles whose tail gas does not meet emission standards (yellow tags); (4) adoption of special policies to invest money taken from penalties in transportation and environmental improvement actions; and (5) long-term and infrastructural interventions to control transport-related air pollution. In summary the results confirm that (e.g. Mediavilla-Sahagun and ApSimon, 2006) no traffic management schemes adopted independently perform effectively but integrated systems; as well, strategies that successfully converge towards compliance are not possible on short timescales. The methodology framework showed in this paper uses a large amount of data and time; therefore, its results need to be evaluated by the stakeholders and then a further optimization may be required. Stakeholder participation is a key requirement of good model development, particularly when models are to address management questions (Fath and Beck, 2005; Hare et al., 2003; Letcher and Jakeman, 2003).

4. Conclusions

This paper describes a new methodology to allow the communication between transport emissions and air quality; the main outcomes are discussed based on its application through the feasibility study and system design of the Beijing ITS-TAP project. The establishment of the commercial equipment is currently under way in Beijing and its test-run should be addressed in future works. This paper was intended to better understand how the improvement of transport technology, both private and public, the reduction of vehicles pollution proportion by technological, political and scientific measures and the improvement of emission performances, could be integrated with ‘‘intelligent’’ transport management system. The integrated system was designed for the real case of Beijing in a modular style to increase the flexibility and extendibility of its components, and shows that the existing air quality tools can be linked through interfaces to account for traffic-related air quality issues. The results from the Beijing case-study show that the integration of the modelling to interpret the data measured with the measurements to validate the data modelled can offer useful tools to assess in real-time traffic-related air pollution.

However, there remains a need to continue research to improve our understanding of the mechanisms leading to air pollution impacts from transport emissions, to reduce the

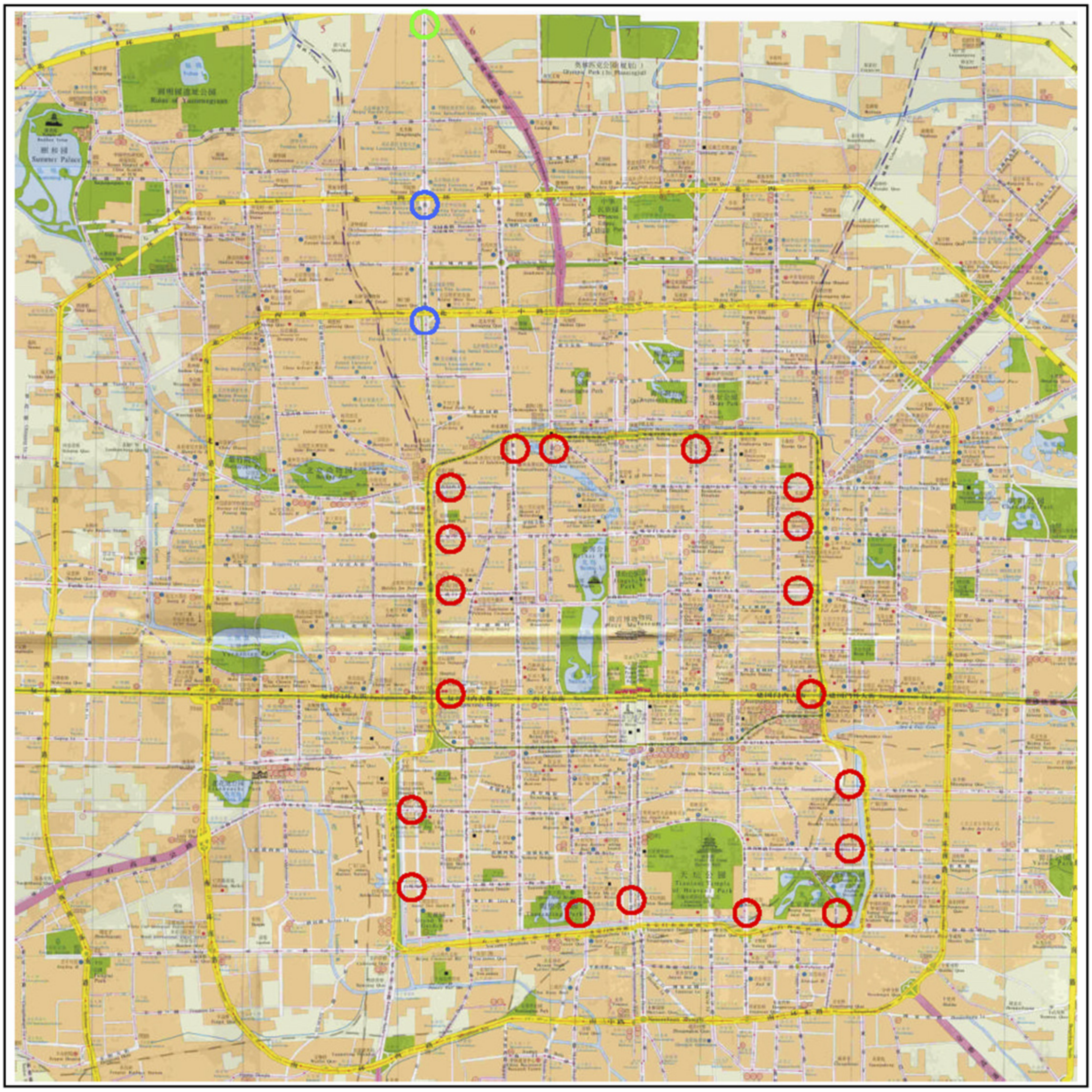

Fig. 12. Beijing's ITS-TAP. Location of the Traffic monitoring stations (Red circles refer to TMS for plate reading, vehicles typology recognition and flow counting. Blue circles refer to TMS for vehicles typology recognition and flow counting. Green circles refer to TMS for flow counting). (for interpretation of the references to colour in figure legends, the reader is refered to the web version of this article).

uncertainty in our ability to quantify the relationships between all emissions and all impacts. For urban air pollutants from road traffic there remain some doubts concerning both the existence and the mechanisms of cause and effect, especially for NO_2 and particles, which are currently two of the air pollutants causing most concern. The integrated assessment modelling has not yet been widely applied to the comparison of such different impacts on urban air quality and upper troposphere chemistry, but its application to future integrated transport systems has the potential to be extremely valuable and would therefore be an intellectually challenging and worthwhile development to pursue.

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