The presentation of an integrated microsimulation modeling framework to measure and predict emissions and dynamic exposure

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Abstract

In this paper, an integrated modelling methodology for the assessment of population exposure to air pollution, involving all compartments of the DPSIR-concept, is illustrated by an application in The Netherlands. The application demonstrates the advantages of an activity-based approach by presenting three kinds of applications: the calculation of vehicle emissions, the simulation of pollutant concentration patterns and the assessment of the population exposure to air population. Understanding exposure variations among activities and subpopulations can be very useful for scientific and policy purposes: it can provide information on locations or population groups most at risk, or can indicate where and when the largest exposure values occur.

1. Introduction

The rapid economic development in most Western countries has led to a quasi linear growth in the yearly number of vehicle miles traveled since the 1970's. In addition to congestion and traffic safety problems that this tendency brings along, traffic is also an important cause of environmental pollution and damage to health. Numerous studies indicate that air pollution increase the risk of development of cancer and allergy diseases or aggravate the condition of people suffering from air ways or heart diseases.

Due to the negative effects of transport, one of the key challenges of the modern policy making consists of promoting a sustainable transportation system aiming at the prevention or reduction of the negative effects of the transportation system on health and environment. It is therefore not surprising that governments today are considering several traffic policy measures to reduce the negative effects of the increasing mobility on the environment. While formulating policy measures concerning traffic and transportation, a number of considerations with regard to health, traffic safety, environment, etc. needs to be taken into account enabling as such an evaluation of the strategies producing the best net advantages in an integrated manner. However, analytic tools enabling an integrated assessment often lack, or are inadequate and insufficient.

To give more accurate and complete estimates on the impact of (transport) policies on the environment, the use of an integrated exposure modelling framework, taking into account the different causal links between activities, trips, emissions, concentrations and exposure, is preferred. Such an integrated approach to describe and mitigate environmental problems is also present in the DPSIR-chain, developed by the RIVM in the late 1980'ties and later adapted by the European Environmental Agency. The DPSIR is a conceptual model used to describe and analyse environmental problems. Driving forces (D) like transport and industry lead to environmental pressures (P) that degrade the state (S) of the environment that has an impact (I) on human health or the environment which makes the society carry out a response (R) through various actions.

2. Project goals and objectives

This proposal, which was carried out in the context of Ph.D. research, involved all the compartments of the DPSIR-concept. First the activities and the travel demand of people were modeled (D), then the emissions resulting from the modeled vehicle trips were simulated (P), the concentrations and the exposure of people to these pollutant concentrations are calculated (S) and the health impact (I) can be assessed. Finally, this exposure model can be used as a tool for evaluating various responses (R) by recalculating all the values in the different compartments for a certain scenario.

To this end, an integrated modelling methodology for the assessment of population exposure to air pollution can be developed and evaluated. To illustrate the feasibility of this concept, an application in The Netherlands is presented. Three main goals emerge: we will (i) calculate and validate the emissions resulting from passenger vehicle trips by using the trip information from an activity-based model, (ii) calculate and validate the pollutant concentrations by converting the activity-based emissions into ambient pollutant concentrations and (iii) establish a population exposure model using the time series population information from an activity-based model and temporal air quality data.

3. Methodology

3.1. Activity-based modeling

Modelling traffic patterns has always been a major area of interest in transportation research. The mainstream of models are often referred to as Four-Step trip-based models (trip generation, trip distribution, modal split and assignment). Many of these aggregate Four-Step models failed to make accurate predictions. The major drawback clearly is the focus on individual trips, where the spatial and temporal interrelationships between all trips are ignored. Furthermore, another drawback clearly is the complete negation of travel as a demand derived from activity participation decisions.

The major idea behind activity-based models on the other hand is that travel demand is derived from the activities that individuals and households need or wish to perform, with travel decisions forming part of the broader activity of scheduling decisions. Travel is merely seen as just one of the attributes. Moreover, decisions with respect to travel are driven by a collection of activities that form an agenda for participation. Travel should therefore be modelled within the context of the entire agenda, or in other words, as a component of an activity scheduling decision. Activity-based approaches aim at predicting which activities are conducted, where, when, for how long, with whom and the transport mode involved. The main advantage, apart from the higher level of detail which is involved in activity-based models is that they are able to evaluate the impact of policy measures on travelers' responses, and due to this, the impact on travel behaviour and air quality can be better assessed.

Although the advantages of an activity-based approach for air-quality purposes are well-known, models that have been developed along these lines are still scarce. For use within the exposure modelling framework, the Albatross and Feathers activity-based models were selected. The models are unique in that 'decision rules' as opposed to 'principles of utility maximization' underlie the scheduling decisions. To simulate activity-travel patterns for a whole population, information on both the population characteristics and their activity-travel patterns is required. Other necessary input data include physical information about the study area.

3.2. Emission modeling

The emission selected for the current work, is the macroscopic MIMOSA emission model. The MIMOSA emission model was developed by Mensink et al. [2] for the city of Antwerp. Later the model was further extended and improved by Lewyckyj et al. [1] to calculate emissions and emission reduction scenarios for larger areas in Belgium (e.g. Schrooten et al. [3]). In order to calculate the vehicle emissions, MIMOSA requires input information on the the road network and the traffic situation.

The required traffic information for the modelling of emissions is the amount of vehicles passing on each traffic link. This information originates from the Albatross and Feathers traffic models. Emission factors are used to convert the vehicle distances into emissions.

3.3. Dispersion modeling

Calculating emissions is useful for environmental policy, but it is not sufficient to study human exposure to air pollution. Dispersion models are needed to convert the emissions into concentrations at which the population is exposed. Over the past decade several modelling tools were developed to assess air quality at various scales, ranging from the local scale to the continental scale. For application within the current modelling framework, the AURORA large scale dispersion model was used.

AURORA, Air quality modelling in Urban Regions using an Optimal Resolution Approach, is a prognostic 3-dimensional Eulerian box model of the atmosphere. The model assesses how, after being emitted from a source, air pollutants are transported and mixed in the air, undergo physical changes and chemical reactions, generate secondary pollutants, etc. Both air pollutants in the gaseous and the particulate phase are taken into account. The model's outcome are 3-dimensional concentration fields, giving an overall assessment of the air quality for the region of interest, and this from the ground up to approximately 20 km altitude. AURORA provides concentration fields on an hourly basis, allowing for the assessment of the hourly and daily variation in air pollution levels.

In order to calculate pollutant concentrations, AURORA requires information about the meteorological conditions, the amount and location of emitted pollutants and the physical situation of the study area.

4. Results and applications of the integrated methodology

4.1. Linking an AB transportation model with an emissions' model

In a first application, the use of an activity-based model for the assessment of mobile source emissions was tested. To this end, the total amount of vehicle emissions produced by passenger cars in the Netherlands and the distribution of emissions across space and time was assessed. By converting the predicted travel behaviour into emissions and comparing the results with values from the Dutch Scientific Statistical Agency, the model's ability to replicate base year travel behaviour and emission assessment with good accuracy was verified.

Regarding the temporal variation in travel behaviour, the activity-based predictions corresponded well with the reported Dutch National Travel Survey (NTS) results. Both the timing and the magnitude of the morning traffic peak were predicted with good accuracy by the activity-based model. The prediction for the evening peak on weekdays slightly differed from the NTS values, but the overall picture of the temporal variation turned out very well. The feasibility to model the temporal variation in travelled distance instead of using only peak-hour information is an important improvement compared to most other travel studies (e.g. Schrooten et al. [3]) who often work with time factors to derive hourly information from one peak-hour value. When the traffic flows fluctuate differently throughout the study area, this activity-based approach will certainly be a better option.

Concerning the distance travelled, the activity-based approach overestimated the total travelled distance approximately by 8% compared to the NTS values. The results of the emission assessments varied between pollutants. For the CO_2 emissions the estimated value differed approximately 11% from the reported value. The SO_2 emissions differed 26% from the published value. The predictions for NO_X, VOC and PM differed from their reported counter values for 16%, 9% and 3% respectively. Considering the fact that we overestimated the vehicle kilometres compared to the NTS values, these relative differences are quite small and probably the amount of PM emissions is still underestimated.

The validation test in this study is an essential first step: if a model is unable to replicate its base year behaviour, it has little hope of forecasting the future adequately. Based on the results of this research we can conclude that the activity-based modelling approach is able to reproduce base year conditions with sufficient accuracy.

4.2. Linking an AB transportation model with a dispersion model

In a second application, the use of an activity-based model for the assessment of air quality was tested. To this end, we combined the activity-based model with the Aurora air quality model to estimate concentrations of PM_{10}, O_3 and NO_2 across space and time. By comparing the predicted hourly concentrations with actual measurements we evaluated the ability of the Albatross - Aurora model chain to replicate base year concentration profiles in different areas and time periods.

The results of the statistical analysis demonstrate that the modelling framework is able to predict hourly concentration values for NO_2, PM_{10} and O_3 with sufficient accuracy. The best agreement between modelled and observed concentrations was calculated for O_3 while the overall agreement for PM_{10} was weaker. The statistical results for NO_2, a traffic related air pollutant, are the most important in this study, considering the fact that we wanted to evaluate the use of an alternative transport model to give good estimates of the contribution of traffic sources to ambient pollutant concentration levels.

In comparison with other model validation studies our study included an extended dataset with hourly concentration data from more than 30 measurement stations distributed throughout the Netherlands. The agreement of predicted and measured concentrations of our modelling system was very similar to the statistical results presented in the other papers, indicating that the Albatross - Aurora system is definitely able to simulate both temporal and geographical variations of concentrations with sufficient accuracy.

The results in this study demonstrate the ability of the Aurora model to simulate hourly concentrations of NO_2, PM_{10} and O_3 and show that an activity-based model can be used to predict the contribution of traffic sources to local air pollution with sufficient accuracy. This result confirms the usefulness of activity-based transport models for air quality purposes, but demonstrates for the first time their application in pollutant concentration modelling.

5. Conclusions

In summary, this project demonstrated the advantages of an activity-based approach by presenting three kinds of applications: the calculation of vehicle emissions, the simulation of pollutant concentration patterns and the assessment of the population exposure to air pollution.

By using the population information from the activity-based simulation, hourly population maps could be made and dynamic exposure values could be estimated. As a result of this, a dynamic exposure modelling framework was established. By applying this framework on a Dutch urban area, we demonstrated the importance of taking into account people's travel behaviour when calculating the exposure. The exposure study in the Dutch urban area demonstrated that large inflows of people occur during the day in the urban areas, causing people to be exposed to higher concentration values compared to their residential situation. Traditional exposure studies that link concentration values with residential information therefore often underestimate the exposure values. Understanding exposure variations among activities and subpopulations can be very useful for scientific and policy purposes. It can provide information on locations or population groups most at risk, or can indicate where and when the largest exposure values occur.

References

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