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The contribution of activity-based transport models to air quality modelling: A validation of the ALBATROSS–AURORA model chain

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ABSTRACT

The potential advantages of using activity-based transport models for air quality purposes have been recognized for a long time but models that have been developed along these lines are still scarce. In this paper we demonstrate that an activity-based model provides useful information for predicting hourly ambient pollutant concentrations. For this purpose, the traffic emissions obtained in a previous application of the activity-based model ALBATROSS were used as input for the AURORA air quality model to predict hourly concentrations of NO_2, PM_{10} and O_3 in the Netherlands. Predicted concentrations were compared with measured concentrations at 37 monitoring stations from the Dutch air quality monitoring network. A statistical analysis was performed to evaluate model performance for different pollutants, locations and time periods. Results confirm that modelled and measured concentrations present the same geographical and temporal variation. The overall index of agreement for the prediction of hourly pollutant concentrations amounted to 0.64, 0.75 and 0.57 for NO_2, O_3 and PM_{10} respectively. Concerning the predictions for NO2, a major traffic pollutant, a more thorough analysis revealed that the ALBATROSS–AURORA model chain yielded better predictions near traffic locations than near background stations. Further, the model performed better in urban areas, on weekdays and during the day, consistent with the emission results obtained in a previous study. The results in this paper demonstrate the ability of the activity-based model to predict the contribution of traffic sources to local air pollution with sufficient accuracy and confirms the usefulness of activity-based transport models for air quality purposes. The fact that the ALBATROSS–AURORA chain provides reliable pollutant concentrations on hourly basis for the whole Netherlands instead of using only daily averages near traffic stations is a plus for future exposure studies aiming at more realistic exposure analyses and health impact assessments.

1. Introduction

In the early nineties, the US Department of Transportation supported four projects to examine how transportation planning models could and should be improved to properly address both the impacts of new transportation technologies and the need for real policy sensitivity, particularly relative to air quality considerations (Spear, 1996). Three of the four proposals recommended that the former trip-based methodologies be replaced by activity-based approaches. Whereas the trip-based transport model focuses on individual trips and ignores the spatial and temporal interrelationships between these trips, the activity-based model is able to examine questions that involve the linkages between a set of travel decisions and activities. Partial and fully operational activity-based micro simulation systems include the Micro-analytic Integrated Demographic Accounting System (MIDAS) (Goulias and Kitamura, 1996), ALBATROSS (Arentze and Timmermans, 2000), Florida's Activity Mobility Simulator (FAMOS) (Pendyala et al., 2005) and the Travel Activity Scheduler for Household agents (TASHA) (Miller and Roorda, 2003; Roorda et al., 2008). Other activity-based models are currently used in New York City (Vovsha et al., 2002) and San Francisco County (Bradley et al., 2001). Good overviews of the activity-based modelling approach and descriptions of the main characteristics of activity-based models can be found in Timmermans et al. (2002) and McNally (2000).

Activity-based approaches aim at predicting which activities are conducted, where, when, for how long, with whom and, if travel is involved, the transport mode used. By assuming the ‘activity’, instead of the ‘trip’, as the basic unit for transportation analysis, and incorporating constraints such as interpersonal dependencies among household members this activity-based approach is much better suited to estimate people's travel behaviour and support the

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decision making process in both transport and environmental policy. Concerning the field of emission analysis, using an activity-based approach will provide more accurate estimates of the emissions produced in a certain study area due to the richer set of concepts which are involved in activity-based modelling (information on travel by time of day and location, the exact time between trips, vehicle miles travelled,…). Also the link between the activity or trip purpose and the resulting emissions is known which is an obvious advantage for policy purposes. Good summaries of the advantages of an activity-based approach for emission analysis can be found in Recker and Parimi (1999) and Shiftan (2000), and more recently also in Beckx et al. (in press). Applications that combine an activity-based model with an emission module are described in Recker and Parimi (1999), Shiftan and Suhrbier (2002) and Hatzopoulou et al. (2007). The most recent accomplishment in this line of research concerns the integration of the MIMOSA2.0 emission model with the travel demand modelling capabilities of the Dutch ALBATROSS model (Beckx et al., in press). Validation results from this latter study indicated that the total amount of emissions predicted by the ALBATROSS–MIMOSA model chain corresponded well with reported emission values from the Dutch statistical agency. However, that validation analysis only compared the results from two different emission models without evaluating the situation on the spot, and only aggregated emission results were evaluated. By converting these emissions into concentrations, a more accurate validation analysis can be performed using the actual measurements in the study area and examining also the temporal and spatial variation of the predictions. Taking into account that the activity-based approach provides more detailed information on pollutant emissions, one can expect the activity-based approach to also contribute to more accurate concentration modelling results. However, up till now, no activity-based air quality framework has ever been developed that converted the calculated emissions into concentrations.

Perhaps the most important advantage of using an activity-based approach for air quality purposes, is that it enables a much better analysis of exposure. The classical approach towards exposure modelling has been to combine pollutant concentration data from air quality models or from fixed monitoring stations with static residential address information (Scoggins et al., 2004). The receptors (i.e. the people) are considered to be always at home and, therefore, only exposed to pollutants at their home address. Beckx et al. (2009) however already demonstrated for a large city in the Netherlands that more realistic exposure estimates can be obtained by taking into account that an important fraction of the population moves in and out of the city during the day and will therefore face very different concentrations of air pollution than at their home address. Since activity-based models can provide information on people's location (based on their simulated travel behaviour during the day), an activity-based model can contribute to more realistic exposure analyses by providing detailed population distributions for the study area. An even more substantial improvement for the exposure estimates can be achieved by using concentrations from an air quality model instead of data from ambient monitoring stations. Epidemiological studies that assess the relationship between air pollution and adverse health effects typically use concentrations from one or more fixed monitoring stations as a proxy for estimating personal air pollution exposure. The assumption hereby is that concentrations are homogeneous over an entire area. However, recent research has highlighted the fact that this assumption is not always true – measurement data from the fixed stations do not necessarily represent areas beyond their immediate vicinity – leading to the potential for error in long-term epidemiological study designs (Kousa et al., 2002; Wilson et al., 2006; Beckx et al., 2008). By using the information from the activity-based model both for the estimation of people's location and for estimating the impact of the performed vehicle trips on pollutant concentrations, an integrated activity-based exposure framework can be established. Such an integrated system does not only provide more accurate dynamic exposure assessments by taking into account that both the people and the concentrations vary in time and space, but is also useful for environmental and transport policies. For a given (transport) policy the impact on the travel behaviour, the emissions, the concentrations and the exposure can be evaluated simultaneously in such an integrated framework. But clearly, before drawing any conclusions on the exposure results, first the concentrations from the activity-based air quality framework need to be thoroughly evaluated against real world measurements.

The aim of this paper is to present and validate an integrated activity-based air quality modelling framework. For this purpose, the activity-based model ALBATROSS (Arentze and Timmermans, 2000, 2005) was integrated with the AURORA dispersion model to calculate pollutant concentrations in the Netherlands. In a previous study by Beckx et al. (in press) the ability of the ALBATROSS model to replicate both travel behaviour and emissions with good accuracy and precision was already demonstrated. In the current paper we validate the calculation of pollutant concentrations resulting from this activity-based chain of models.

The remainder of this paper is organized as follows. In the next section, the development of an activity-based air quality modelling framework in the Netherlands is described, using the activity-based model ALBATROSS to assess people's travel behaviour and the resulting vehicle emissions, and the AURORA air quality model to calculate the concentrations. This section also describes the data from the Dutch monitoring network that were used for the validation analysis. In Section 3 the model results are compared with measured results from the measurements stations. Validation results for PM_{10}, NO_2 and O_3, are presented and discussed, and the model results are compared with statistical results from other validation studies. Finally, we conclude this paper with some thoughts on future research.

2. Methodology

To illustrate the activity-based approach for air quality modelling, we have used the emission information from a previous application of the activity-based model ALBATROSS as an input for the AURORA dispersion model to calculate pollutant concentrations in the Netherlands. This section briefly presents the different components of the activity-based air quality modelling chain and also describes the data that were used to validate the model results.

2.1. The activity-based model ALBATROSS

The activity-based model ALBATROSS, A Learning-Based Transportation Oriented Simulation System, was developed for the Dutch Ministry of Transportation, Public Works and Water Management as a transport demand model for policy impact analysis. ALBATROSS is a computational process model that relies on a set of decision rules, which are extracted from observed activity diary data, and dynamic constraints on scheduling decisions, to predict activity-travel patterns for individuals within the Dutch population (Arentze et al., 2003; Arentze and Timmermans, 2000). The model is able to predict for every person in the population which activities are conducted, when, where, for how long, with whom, and the transport mode involved. In a subapplication of the model, a synthetic population can be created with iterative proportional fitting methods, using demographic and socio-economic geographical data from the Dutch population and attribute data of a sample of households originating from a large national survey. The ALBATROSS 2.0 model version used here is estimated on approximately 10,000 person-day activity-diaries collected in a selection of regions and neighbourhoods throughout the Netherlands and the sample used for the iterative proportional fitting included approximately 67,000 households (Arentze and Timmermans, 2005).