Shop opening hours and population exposure to NO_2 assessed with an activity-based transportation model

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Abstract

In this work we assess for the first time the impact of a policy measure on population exposure to NO_2 by using the activity-based model ALBATROSS, the emission model MIMOSA and the dispersion model AURORA. We found that widening shop opening hours changes the activity pattern of the adult population in the Netherlands. It increases kilometres driven and, as a consequence, emissions. When matching the concentration maps with the dynamic population, we observe an increase in population exposure to NO_2.

Introduction

The most straightforward way of determining population exposure is by making use of concentrations measured at fixed monitoring stations in combination with data on population density. Although this is a simple and commonly used methodology, it does not represent actual population exposure because it ignores movement of people and concentration variations on a local scale. The second issue is dealt with in numerous studies by applying interpolation maps to introduce spatial variation. The first issue is much harder to take into account.

A decade ago Shiftan [1] already explored the advantages of activity-based modelling for air-quality prediction purposes. An activity-based model basically predicts a diary for every individual: which activities will be performed where and for how long and if a trip is involved which transport mode will be used [2, 3]. By using an activity-based transportation model we can improve on both of the issues stated above: we can use dispersion modelling based on more accurate emission estimates of modelled trips and we can model the location of every individual for every hour of the day. This way a truly dynamic exposure analysis can be made by geographically matching hourly concentrations and hourly population densities. Moreover, we are able to differentiate between different subpopulations and different activities allowing a more detailed exposure analysis.

This methodology has the potential to provide valuable information for air pollution epidemiology [4] and policy purposes [5]. As an example this paper will look at a scenario (widening of shop opening hours) and evaluate the effects on population exposure.

Methodology

The modeling framework will be summarized in a nutshell since this is not the main focus of this paper. An extensive description of the framework can be found in Beckx et al. [6-9].

Activity-based transportation model

The activity-based transportation model ALBATROSS, an acronym for A Learning Based Transportation Oriented Simulation System, was used to predict activity-travel patterns for the Dutch population [10, 11]. The model starts by developing a synthetic population using demographic and socio-economic geographical data from the Dutch population and attribute data of a sample of households originating from a national survey including approximately 67,000 households. Every adult inhabitant of the Netherlands (or more precisely, household head), is incorporated in the synthetic population. The 4-digit postal code area (4PCA) was chosen as the spatial unit for the ALBATROSS model.

Activity-travel schedules are simulated for all the individuals by using decision trees representing each choice (e.g. a stochastic choice of activity type, duration of activity, choice of location, transportation mode involved, etc.). While making these decisions several constraints, e.g. institutional constraints and household constraints, are taken into account to make resulting activity diaries more realistic. We used the output of one run of the model representing one-day diaries across all days of the week of all people in the study area. Thus, the activity patterns should be representative for an entire week. Presently, possible seasonal differences in weekly activity patterns are not captured. To predict traffic flows, we extract from the activity patterns generated O/D-trip matrices. Those predicted trips for the entire population are assigned to a road network ('Basisnetwerk') by using an all-or-nothing assignment (shortest path in distance).

Emission model

Traffic flows are converted into vehicle emissions by applying the emission factor approach from the MIMOSA emission model [12].

Dispersion model

In a next phase, the activity-based approach is further extended by converting the emissions into pollutant concentrations. For this purpose, the AURORA model is applied to simulate the dispersion and conversion of the emissions into concentrations [13].

Integration of the models

The goal of the modelling framework is to assess population exposure both in the base case, as well as in a scenario. The predicted hourly concentration fields from the ALBATROSS-MIMOSA-AURORA modelling chain are combined with hourly information on people's location to calculate the exposure. By using the population information from the activity-based simulation, hourly population maps are simulated and dynamic exposure values can be estimated (Figure 1).

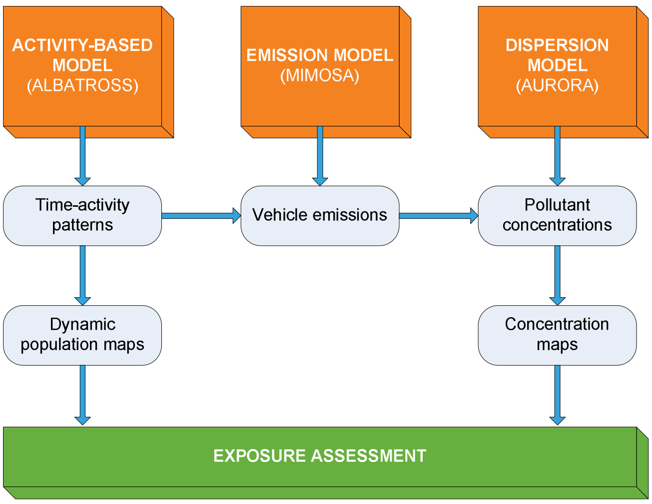

Fig. 1. The exposure modelling framework

Each step in the process is evaluated to assess modelling power. As it appears, a comparison between the modelled emissions and reported emission values demonstrate good correspondence. When comparing the simulated concentrations for the base case with measured values at Dutch monitoring stations, the index of agreement varies between 0.40 and 0.70 for NO_2 [6], which demonstrates that the activity-based air quality model chain is able to simulate the hourly concentration patterns in the Dutch study area with sufficient accuracy.

Results and discussion

The scenario considered involves a widening of shop opening hours for daily and non-daily shopping. The new opening hours are from 6 a.m. until 10 p.m. on weekdays and Saturdays, which allows shopping earlier in the morning and later in the evening. As a tendency, this is a relevant policy scenario keeping in mind that liberalization of shopping hours in the Netherlands is relevant continuously already since 1996.

As a case study we model the exposure difference for NO_2 of the adult population of the Netherlands (approximately 10.5 million individuals).

Results

Effects on the activity pattern

As a consequence of the scenario, the ALBATROSS model predicts approximately 6% more non-daily shopping hours and 0.5% more daily shopping. The change in activity pattern results in more transport hours; an increase of 0.5%. This increase is translated in more kilometres driven by car. In a study of Jacobson [14] an augmentation in weekly shopping time was observed as well, both from a simple model and from empirical findings.

On an average weekday, shifts are seen during the day (Figure 2). As expected, there will be more shopping in the morning and in the evening. This is offset by less time spent on in-home activities and on leisure. Between 8 a.m. and 5 p.m. there will be somewhat less shopping compared to the reference situation.

In the reference situation and in the scenario women execute more shopping-activities than men. Both men and women adapt quite similarly to the new opening hours and the same temporal pattern can be observed.

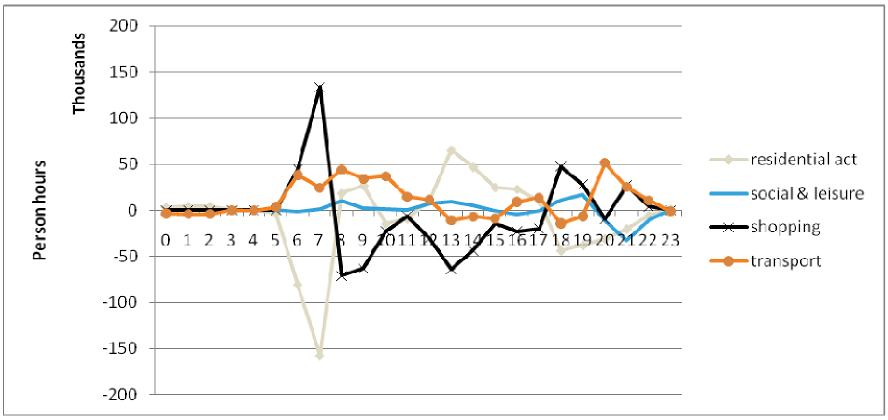

Fig. 2. Difference in activity pattern between scenario and reference situation on an average weekday per hour of the day (on the x-axis the hours of the day are represented)

Effects on concentrations

The ALBATROSS model showed more kilometres driven by car; as a consequence emissions of road transport will rise (output of the MIMOSA-model) as well as the derived concentrations in ambient air (output of the AURORA-model). The activity pattern is assumed the same for every week of the year, but the meteorological conditions change so concentrations will differ from week to week.

The concentration maps use a raster overlaying the Netherlands, one grid cell being 9 km² (a total of 11439 grid cells) (Figure 3).

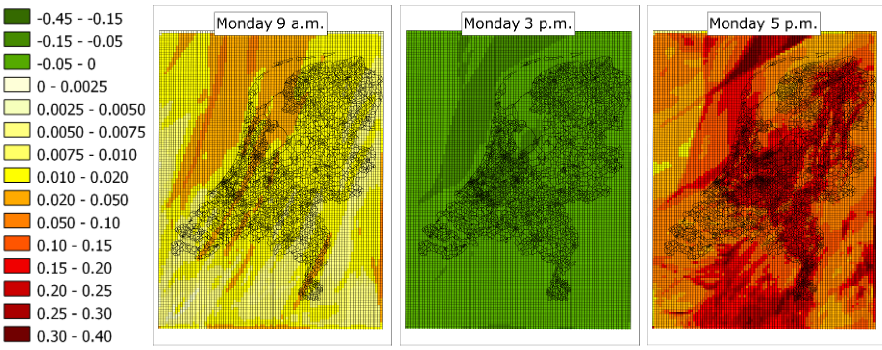

Fig. 3. Difference in concentration levels (µg/m³) between scenario and reference situation on three moments on Monday the 4th of April 2005

Generally concentrations are higher in densely populated and in industrialized areas. Around major highways elevated levels of NO_2 are observed. In the North Sea a wedge of higher concentrations can be observed on shipping routes. The direction of plumes is clearly affected by the wind direction; in the illustration (Figure 3) wind direction was southwest, the most prevailing wind direction in the Netherlands.

On Figure 3 the differences in concentration levels between the scenario and the reference situation are presented. Absolute differences are small as expected (maximum difference of 0.40 µg/m³). Above the North Sea remarkable differences exist between the current situation and the situation where shop opening hours are widened. We did not yet find an explanation for this and it may be caused by assumptions made in the AURORA-model. The sensitivity of AURORA to scenarios with little or no impact is rather limited, caused by uncertainty introduced by each of the models.

Effects on exposure

Total exposure is calculated multiplying dynamic population in the postal code area with concentrations in the grid cell. All calculations were performed for April 2005.

Results show an increase in population exposure to NO_2 (Figure 4). On an average weekday in April exposure will increase with 0.15 µg/m³. This number is relatively stable across the days of the week. At night-time and on Sundays the difference between the base-situation and the scenario is negligible, which is a reassuring result. Tested over several weeks the relative change in exposure on an average weekday is 0.4%.

In certain neighbourhoods and on certain hours a more substantial increase can be observed (Figure 5).

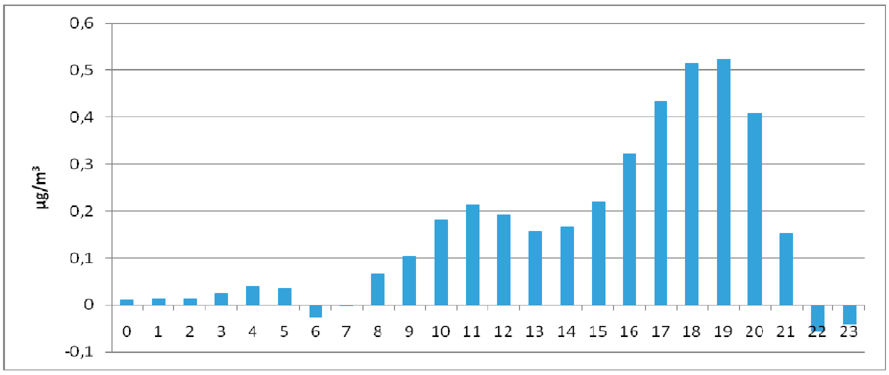

Fig. 4. Difference in exposure between scenario and reference situation on an average weekday per hour of the day for April 2005 (on the x-axis the hours of the day are represented)

The increase in population exposure is statistically significant. The numbers in Table 1 are corrected for postal code areas with a low number of people residing there (less than 100) because a ratio of small values can cause inconsistent results.

Table 1. Difference in exposure between scenario and reference situation (April 2005) [µg/m³]

April	Week 1	Week 2	Week 3	Week 4
Monday	0.1079	0.1599	0.1223	0.1441
Tuesday	0.1163	0.1421	0.1323	0.1487
Wednesday	0.1168	0.1662	0.1174	0.1232
Thursday	0.1122	0.1741	0.1935	0.2165
Friday	0.2113	0.1154	0.1852	0.2371
Avg weekday	0.1329	0.1515	0.1501	0.1739
Saturday	0.1592	0.0881	0.1472	0.1696
Sunday	0.0614	0.0657	0.0604	0.0677
Avg week	0.1265	0.1302	0.1369	0.1581

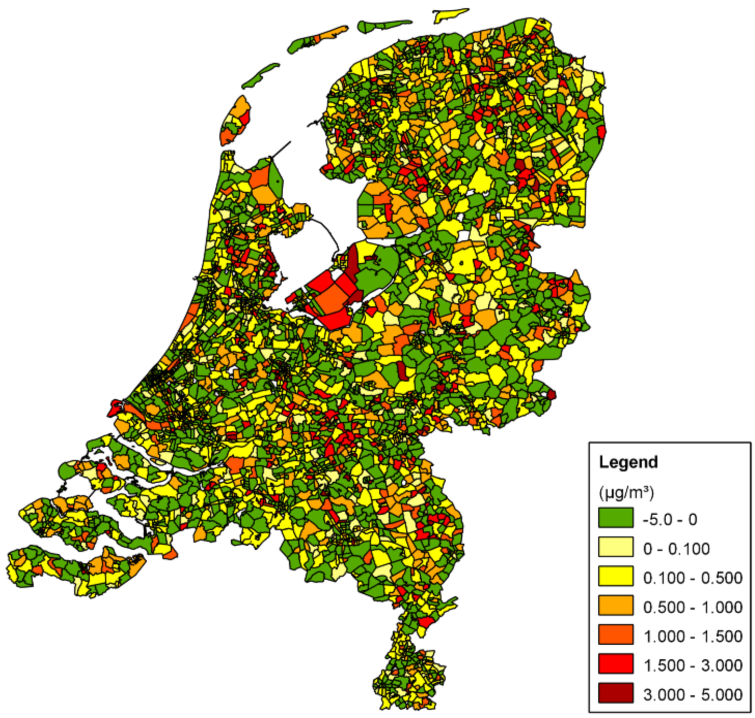

Fig. 5. Difference in exposure between scenario and reference situation on an average weekday geographically represented per postal code area

Discussion

Since the early 1970s, the EU has been working to improve air quality and much progress has been made since then. However air pollution continues to be a matter of concern. Several European, national or regional policy measures explicitly aim at lowering concentrations of harmful pollutants (e.g. through legislation or vehicle technology). There is a lack of awareness that other measures, not explicitly focussing on air quality, will significantly impact exposure and health both in a positive and in a negative way. It may happen that expensive measures to cut emissions and lower concentrations are offset by initiatives from other policy makers who are not aware they are affecting air quality. Prolonging shop opening hours is such a measure that has an unintended negative side-effect on population exposure, although the effect is only limited.

Activity-based transportation models are proven to be better in evaluating the effect of TDM (travel demand measures) and integrated policies because of their ability to incorporate secondary effects [1]. Examples of TDM are traffic restraint measures, pricing mechanisms, telecommunication or high-occupancy vehicle lanes. Next to transportation measures, activity-based models are able to calculate the effects of certain scenarios having no obvious relation with transport or air quality. Institutional changes (e.g. changing working hours, changing shop opening hours) or demographical changes (e.g. ageing of the population [15], changing percentage of part-time workers, more one-adult households) can be assessed with an AB-model, all being evolutions relevant to policy nowadays.

So far and to the best of our knowledge, there are hardly any papers on the modelled quantitative effects of policy measures on air pollutant concentrations, population exposure and health for larger geographical areas. One of the first papers of this sort looked at the effect of the Congestion Charging Scheme (CCS) in London [16] which affected an area with approximately 7 million inhabitants. This study only considered emissions and not concentration or population exposure. The health effects of the London CCS were assessed by Tonne et al. [17] and they found a decrease in population exposure to NO_2 in the Greater London area of 0.10 µg/m³; in the congestion charging zone the effect was larger (-0.73 µg/m³). A similar study on the Stockholm congestion charging found effects of -0.23 µg/m³ (population exposure to NO_x) [18]. These resulting exposures are observed ex post; after the introduction of a policy measure. Our simulation is valuable in a way that measures can be assessed ex ante. This gives priceless information to governments who want to assess costs en benefits before a policy measure is introduced.

Conclusion

This paper presented the first analysis of a scenario generated with the activity-based model ALBATROSS and the effects on population exposure to NO_2. We demonstrated that by using this approach the effect of a policy measure on population exposure can be assessed. In this paper, we showed that an increase in population exposure of 0.15 µg/m³ is associated with the widening of shop opening hours. Examples of other measures or scenarios that can be evaluated by such an approach are ageing of the population, teleworking, introduction of congestion charging, etc.

As discussed above the sensitivity of the MIMOSA-AURORA chain to scenarios with little or no changes in concentrations is rather limited. Taking into account the complexity of the modelling framework, the required computer runtime and the lack of flexibility, we suggest replacing the emission and dispersion model with a land use regression model. The challenge here will be to adequately incorporate a temporal dimension into the land use regression model.

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