ASSESSING THE MARGINAL IMPACT OF A TRIP ON POPULATION EXPOSURE TO AIR POLLUTION

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ABSTRACT

There are different reasons to assume that not every vehicle kilometre yields the same environmental impact. For instance, some vehicle kilometres are driven at high speeds on highways, while others are driven at low speeds in urban environments. This will have an impact on the resulting exhaust emissions. Furthermore, the timing of a trip determines its impact on the resulting concentration levels. Pollutants emitted during trips at night will have a larger impact on the ground-level concentrations than emissions exhausted during the day, due to the greater atmospheric stability. And, concerning the impact on exposure, emissions produced in cities will affect a larger number of people than emissions exhausted in sparsely populated areas. These aspects are examined in this paper using an integrated model chain involving an activity based traffic demand model (to assess people's travel behavior), an emission model (to convert the trips into emissions) and a pollutant concentration module (to simulate detailed concentration maps and assess the impact of each trip on the resulting concentration level). By combining the model output with detailed population information, the marginal impact of a trip on the population exposure to NO_2 was assessed. Results demonstrate that not every vehicle kilometre and not every trip motive yields the same impact on the population exposure.

1. INTRODUCTION

Previous studies already demonstrated the value of classifying trips by trip motive in order to gain more insights into transport related environmental problems. Beckx et al. (2010) for example focused on the difference between commuter and non-commuter trips. They concluded that commuter trips significantly differed from non-commuter trips in terms of parameters like trip distance, total emissions and total fuel consumption. Further, there are also different reasons to assume that not every kilometre driven by car yields the same impact on the environment in terms of concentration increases or impacts on exposure. The timing of a trip can for example be an important factor since it determines the impact of emissions on the resulting pollutant concentration levels. Pollutants emitted during trips at night or in the early morning will have different impact on the ground-level concentrations compared to daytime exhaust emissions, due to different atmospheric conditions. And, concerning the impacts on exposure, emissions produced in cities will affect a larger number of people than emissions exhausted in sparsely populated areas.

Since trips with different trip motives might differ in aspects like the travelled speed, the trip timing and location, there are reasons to believe that the marginal environmental impact of a vehicle kilometre can differ between different trip motives. This paper therefore examines the marginal environmental impact of different trip motives. The novel approach presented in this paper combines information from a travel model, an emission model and a dispersion module to analyze the specific impact of each trip type on the environment. Concentration results were combined with population information to assess the marginal impacts of a travelled kilometre on exposure to NO_2.

2. METHODOLOGY

The model chain applied in this study includes an activity based model to assess people's travel behaviour ('Feathers'), a traffic emission model to convert trips into emissions ('MIMOSA'), a concentration interpolation tool using measured air quality data ('RIO') and a bi-gaussian plume dispersion model ('IFDM') in order to provide detailed pollutant concentration maps and, as a result, assess the impact of each trip on the resulting concentration levels. For the results presented in this study, model input data for the year 2007 were used and the study area includes the Flanders region and Brussels (i.e. northern part of Belgium), a densely populated area (13522 km²) with approximately 7.4 million inhabitants. Trips were classified by trip motive to provide more insights on the impact of different trips on the environment. The following sections provide a brief overview of the most important modelling aspects. More detailed information on the technical aspects of the individual models can be found in Lefebvre et al. (2011) and/or in selected references (as indicated in sections below). An evaluation of the air quality results from this model chain yielded positive validation results, meaning that simulated concentration levels correspond to measured concentration values with sufficient accuracy.

2.1 Modelling travel demand with an activity-based travel demand model

The activity-based model FEATHERS (Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS) is a microscopic agent-based simulation framework that allows to simulate the activity-travel behaviour of individuals in Flanders and Brussels. It simulates origin-destination matrices for all the agents in a synthetic population based on observed activity diary data and demographic and socio-economic input data. In the current study, the study area was subdivided into 1145 population zones with an average area of 12 km². Origin destination matrices between these zones were simulated for a synthetic population representing approximately 5 million adults living in Flanders and Brussels. Matrices were estimated per hour of the day, for an average week (Monday – Sunday). By applying a traffic assignment algorithm from the Transcad transport model (Caliper), these matrices were assigned to the geographic road network, similar to the approach presented in Beckx et al. (2009). In the current study, trips were classified by trip motive in order to assess the impact of each trip motive on the environment. The motives for every trip are defined by the activity performed at the trip destination. Further, to complete the kilometres for road traffic, the kilometres travelled by heavy duty vehicles for transporting goods are added based on information from the freight model for Flanders. More detailed information on the FEATHERS model can be found in Bellemans et al. (2010).

2.2 Assessing pollutant concentration levels

The traffic loads provided by the Feathers-Transcad modelling step were first converted into vehicle emissions by the MIMOSA4 emission model, a module within VITO's E-motion Road model. MIMOSA4 is the most recent version of the traffic emission model MIMOSA and relies on the COPERT4 methodology for the emission functions and for calculating energy consumption (Gkatzoflias et al. 2007). As a result this model generates hourly emission output, geographically distributed over the study area. For a more detailed description of the MIMOSA emission model we refer to Beckx et al. (2009) where its application to activity-based models is also fully described.

In a next step, the spatially and temporally distributed emissions from the MIMOSA emission model were converted into detailed pollutant concentration levels by combining the land use regression model RIO with the bi-Gaussian plume model IFDM (Immission Frequency Distribution Model). The RIO model is a validated land use regression model for Flanders and the Netherlands (Janssen et al. 2008). RIO estimates hourly pollutant concentrations in a 3x3 km² square, based on the data collected in the official fixed site monitoring network and a land use (CORINE) derived covariate. As an output RIO produces hourly concentration maps. In this study (background) concentrations are provided by this regression method. The IFDM model is a bi-Gaussian plume model, designed to simulate non-reactive pollutant dispersion on a local scale. As IFDM is a receptor-model, it can be used for both regular and irregular grids. On top of the regular 1x1 km² grid an irregular line source following grid was defined to account for the steep concentration gradients along highways (25x800m² close to the roads). This approach is similar to the methodology used by Lefebvre et al. (2011) and ensures that more receptor points are available on the locations where the largest gradients are expected. More information on the IFDM model can also be found in the European Model Database (http://air-climate.eionet.europa.eu/databases/MDS/index_html). The two models, RIO and IFDM, are coupled to cover both the regional aspects of the air pollution (provided by RIO) and the local concentration gradients along major line and point sources (calculated by IFDM). A coupling procedure, eliminating the double counting of traffic emission sources, is used. This is done by eliminating the marginal concentration increase resulting from the traffic emissions on a lower resolution, before adding the concentrations due to these emissions. In order to discern the effect of a trip motive, this subtraction step (eliminating the marginal concentration increase due to the traffic emissions) is first applied, but, instead of adding the effect of all traffic emissions back again to the concentrations, all emissions except those from the motive which we want to investigate are added. Then, the effect of this motive on the pollutant concentrations is the difference between the model run with the emissions from all trip motives, minus the run with one specific motive eliminated. The advantage of this methodology is that one strays not very far from the chemical equilibrium (which would be the case when eliminating all motives, except the one that one wants to investigate).

2.3 Analysing population exposure

In this paper, exposure is defined as a simple passive exposure, based on residential address information. Specifically, we consider that all people within northern Belgium, including those commuting and those inside their residences, are only exposed at their home address. The added value of the exposure assessment lies in the high resolution (up to 5 m) habitation data used in this study. As such, we are able to discriminate in detail the exposure of the considered population. In fact, as there is more traffic in densely populated areas than in non-densely populated areas, the static exposure (i.e. the sum of the multiplication of each person with the corresponding concentration value) will be higher than the multiplication of the regional averaged concentration with the total population. We call the proportion of both factors the population multiplication factor (PMF) and define it thus as follows:

$PMF = \frac{\sum_{people} \Delta C_l}{N \overline{\Delta C}}$, with ΔCl the concentration change at a person's home location when eliminating a specific trip motive, N the number of persons and $\overline{\Delta C}$ the average concentration change over the entire region when eliminating the motive. The exposure per kilometer driven will be given by the multiplication of the emission per km, the concentration per emission and the exposure increase per concentration increase. We call the exposure per kilometer driven the exposure intensity (EI).

3. RESULTS AND DISCUSSION

In Figure 1 a summary is presented of the results from the different modelling steps in this study. Since we are interested in the marginal environmental impact of each trip motive, results are presented per vehicle kilometre. Results per trip motive are expressed relative to the average results for the non-freight trips (distance weighted). The PMF is however calculated according to the formula mentioned previously.

Concerning the emissions per kilometre, the difference between freight and non-freight trips is clearly visible. Much higher emissions per driven kilometre are seen with the freight transport, compared to the other trip motives which are covered mainly with light duty vehicles. Comparing the emissions for the other trip motives, the highest emissions per driven kilometre are found for transit trips what can be explained by a generally higher travelling speed (associated with higher emission rates) for this kind of through traffic. Next, in Figure 1, the concentration changes per exhausted emission reflect the marginal impact of an exhaust emission on the resulting concentration. In contrast to the emission results, where the vehicle type appeared to be the most important factor, the concentration changes are influenced by the moment in time when the emissions are exhausted. For example, the trip motive 'going to work' is generally done in the early morning, when the dispersion is very limited. As a result, an emission produced during a trip to work usually results in larger concentration increases than an emission produced when going shopping during the day or in the early evening. Further, as expected, the PMF in Figure 1 is above 1 for all motives, meaning that concentration changes will generally be larger in densely populated areas compared to sparsely populated areas. As such, the values we get for the PMF demonstrate the importance of using high resolution air quality data for exposure assessment. Furthermore, results show that motives which have a larger fraction of highway use (e.g. freight) have a lower PMF than those which do not have such an abundant highway use. The exception is the transit traffic, which has a high highway use fraction but also the highest PMF of all motives. This is due to the specific distribution of the transit fraction over the region. Most of the transit traffic is generated by Walloons (people from Southern Belgium) travelling to Brussels. The region around Brussels and Brussels itself, however, is very densely populated leading to a high PMF for this type of transport. Many persons living in Flanders also work in Brussels. However, the latter are part of the motive 'working', in which they are combined with people travelling to work in less populated areas. Concerning the exposure results, Figure 1 shows that kilometres travelled for freight transport have a much higher EI than kilometres travelled for the other trip motives. However, this is not so high as could be expected when comparing their respective emission per kilometre. This is due to the previously mentioned low PMF for freight transport, combined with a low concentration increase per emission exhaust. Furthermore, transit traffic exhibits a high EI, mainly due to their high PMF. Finally, the EI is also high for going to work, but this is due to the stronger atmospheric stability in the morning when trips to work mainly take place.

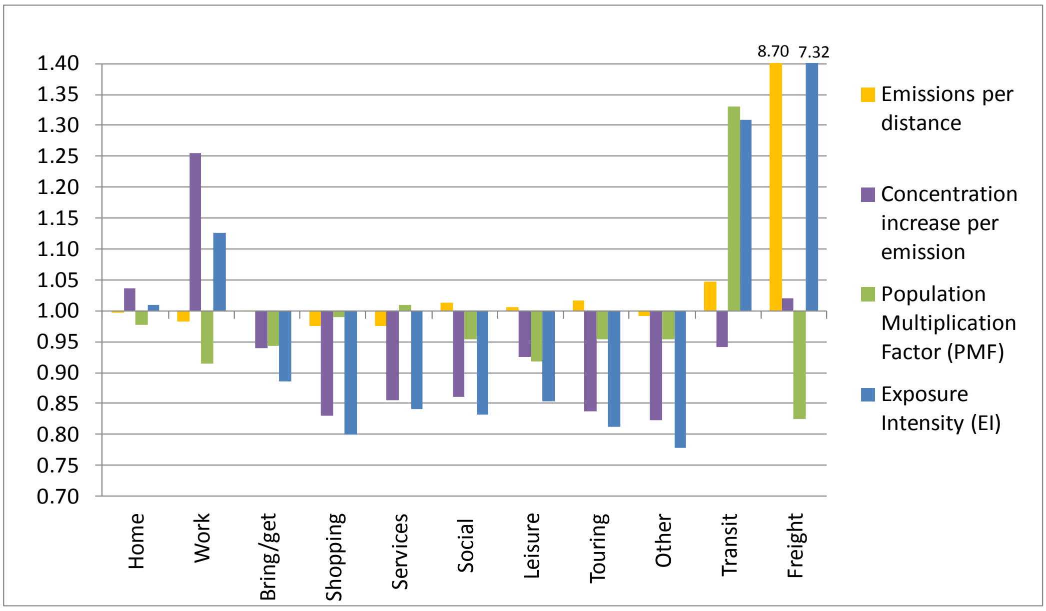

Figure 1: The results for the emissions per distance (g/km), the concentration increase per emission (µg/m^3 per kg), the PMF and the EI (pers*µg/m^3 per km). Results are expressed relative to the results for an average vehicle kilometre (non-freight), per trip motive, for NO_2. In order to clearly present differences between trip motives, the bars for freight transport are not entirely visible, but values are presented separately on top.

4. CONCLUSION

The results in this study demonstrate that not every vehicle kilometre and not every trip motive causes the same impact on the environment in terms of emissions, concentration increases or exposure. It is shown that the following aspects are important: the vehicle type (leading to much higher emissions for freight trips), the time of the day (emissions in the early morning have an important effect on concentration levels due to higher atmospheric stability) and the location (emissions generated in densely populated areas exhibit larger exposure effects than emissions in non-densely populated areas).

5. REFERENCES

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