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Peer-reviewed author version

BECKX, Carolien; Arentze, T.; INT PANIS, Luc & JANSSENS, Davy (2008) Assessing vehicle emissions through an integrad activity-based modelling framework. In: Sànchez-Marrè, Miquel & Béjar, Javier & Comas, Joaquim & Rizzoli, Andrea E. & Guariso, Giorgio (Ed.) Proceedings of the IProceedings of the iEMSs Fourth Biennial Meeting: International Congress on Environmental Modelling and Software (iEMSs 2008)..

Handle: http://hdl.handle.net/1942/9539

iEMSs 2008: International Congress on Environmental Modelling and Software
Integrating Sciences and Information Technology for Environmental Assessment and Decision Making
4th Biennial Meeting of iEMSs, http://www.iemss.org/iemss2008/index.php?n=Main.Proceedings
M. Sànchez-Marrè, J. Béjar, J. Comas, A. Rizzoli and G. Guariso (Eds.)
International Environmental Modelling and Software Society (iEMSs), 2008

Assessing Activity-Related Vehicle Emissions through an Integrated Activity-Based Modelling Framework

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Abstract: Policymakers are increasingly recognizing the importance of source-related measures, instead of technological actions, to tackle the problem of traffic air pollution. Unfortunately, traditional trip-based models fail to make accurate predictions for activity-related policy questions. Due to the richer set of concepts which are involved in activity-based transportation models, the use of these models should be encouraged to contribute to this part. In this research the activity-based model ALBATROSS was used to assess trips and emissions produced by passenger cars in the Netherlands. The results were segregated according to trip motive to gain more insights into the contribution of different trips towards the total amount kilometres and air pollution. The predicted values correspond well with the reported values from the Dutch Scientific Statistical Agency. Predictions for total travelled distance, carbon dioxide, carbon monoxide, nitrogen oxide, sulphur dioxide and particulate matter (PM) differed not more than 8% from the officially reported values. Concerning the classification into trip motive, the commuter trips produced almost half of the PM emissions. Further, trips with a social purpose caused 17% of the PM emissions, and shopping and leisure trips each accounted for 10% of the total PM emissions. This paper is novel in the sense that it reports on the applied methodology and presents the practical results from a case study of the activity-based modelling approach as well.

Keywords: Activity-based modelling; ALBATROSS; Emissions; trip motive.

1. INTRODUCTION

The last few years, there is an increasing concern over the environmental impacts of traffic as traffic volumes have continued to rise. Technological innovations on motor vehicles (e.g. the European directives 91/441/EEC, 94/12/EC and 98/69/EC) are able to diminish the environmental consequences of this increase. However, due to the continuing increase of vehicle kilometres on the road, the results of these improvements will be partially offset, forcing the implementation of other traffic measures. National and local policymakers are therefore recognizing the importance of source-related measures [EEA, 1999]. Unlike technological measures, focusing on the end of the problem chain, source-related measures intervene in an earlier stage of the problem and focus on the demand for travel. Concerning the problem of traffic air pollution, focusing on the source of the problem means concentrating on people's travel behaviour: why are people travelling? Good quantitative information about people's travel behaviour should provide policymakers with the answers to this kind of question.

Unfortunately, questions that involve the linkages between activities and travel decisions can not be examined through a traditional trip-based four-step transportation model. This kind of model focuses on individual trips where the spatial and temporal interrelationships between trips and activities are ignored. Together with other limitations [see e.g. Beckx et al. 2005], this inability has prompted the development of a new approach to travel analysis, the activity-based approach.

This paper presents the first results of a research project that applies an activity-based travel demand model to the evaluation of activity-related exhaust emissions. The activity-based model ALBATROSS, a fully operational computational process model developed by Arentze and Timmermans [2005], was used to predict trip distances and emission estimates for personal vehicle travel in the Netherlands. Trips were classified according to trip motive to gain an insight into the contribution of different trips.

The remainder of this paper is organized as follows. In the next section, the activity-based modelling approach is briefly explained and the activity-based model ALBATROSS is described. Next, the methodology to apply such an activity-based model for air quality purposes is explained followed by a presentation of the results from the trip analysis and emission assessment procedure. Finally, the results are discussed and the paper concludes with some important aspects of future research applications.

2. ACTIVITY-BASED MODELLING OF TRAVEL BEHAVIOUR

2. 1 Introduction

Modelling traffic patterns has always been a major area of concern in transportation and environmental research. Since 1950, due to the rapid increase in car ownership and car use in the US and in Western Europe, several models of transport mode, route choice and destination have been used by transportation planners, often referred to as “four-step models” [Ruiter and Ben-Akiva, 1978]. These models were necessary to predict travel demand on the long run and to support investment decisions in new road infrastructure. A lot of these aggregate four-step models failed to make accurate predictions. The major drawback is the focus on individual trips, where the spatial and temporal interrelationships between trips are ignored. Furthermore, the overall behaviour is represented as a range of constraints which define transport choice, while it is in fact both an outcome of real human decision making and of a complex choice process. The last drawback clearly is the complete negation of travel as a demand derived from activity participation decisions. This is where activity-based transportation models came into play.

The major idea behind activity-based transportation models is that travel demand is derived from the activities that individuals and households need or wish to perform [Ettema and Timmermans, 1997]. Activity-based approaches aim at predicting which activities are conducted, where, when, for how long, with whom and the transport mode involved. An activity-based model allows for spatio-temporal linkages between the collection of activities that individuals and households perform as part of their daily schedule. Besides providing detailed activity-travel information for individuals within a population, the advantages of activity-based modelling lie in its ability to give a better prediction of travellers’ responses to transportation control measures. Over the last years, several research teams have focused on building activity-based models of transport demand [e.g. Bhat et al. 2004; Arentze and Timmermans, 2005; Pendyala et al. 2005]. But, although the potential advantage of an activity-based approach for air-quality purposes has been recognized from the beginning [Spear, 1994] and has been re-iterated more recently [Shiftan, 2000; Beckx et al. 2005; 2007a], to the best of our knowledge- models that have been developed along these lines are still scarce.

2.2 The activity-based model ALBATROSS

The activity-based model ‘A Learning-Based Transportation Oriented Simulation System’ (ALBATROSS) 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, typically extracted from activity diary data, to predict activity-travel patterns [Arentze and Timmermans, 2000; Arentze et al. 2003]. The model is able to predict which activities are conducted, when, where, for how long, with whom, and the transport mode involved.

The activity scheduling agent of ALBATROSS is the core of the system which controls the scheduling processes. The scheduling model of ALBATROSS, which generates a schedule for each individual and each day, consists of three components. The first component generates an activity skeleton consisting of fixed activities and their exact start time and duration. Given the skeleton, the second component then determines the part of the schedule related to flexible activities to be conducted that day, their duration, time of day and travel characteristics. Both components use the same location model component determining the location of activities. All three components assume a sequential decision process in which key choices are made and predefined rules delineate choice sets and implement choices made in the current schedule. Interactions between individuals within households are to some extent taken into account by developing the scheduling processes simultaneously and alternating decisions between the persons involved.

Figure 1 schematically presents the structure of the first model component: the process model for generating fixed activities.

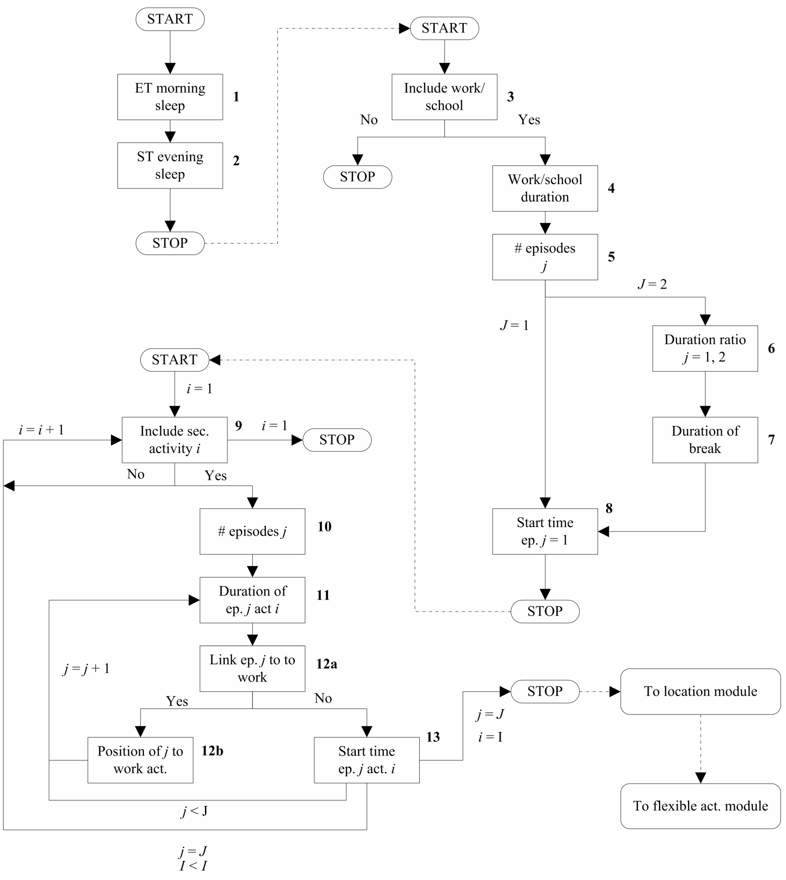

Figure 1. Process model for generating fixed activity patterns (ET = end time; ST = start time, sec. = secondary, ep. = episode, act. = activity)

Each numbered rectangle corresponds to a decision tree. The indices used in the figures are defined as follows: *i* is the index of activity in order of priority, *i* = 1,… , *I* and *j* is the index of episode of activity i in order of start time, *j* = 1, …, *J*. The skeleton component comprises decisions 1 tot 13 and consists of several subprocesses, including determining the pattern of sleep activities (decisions 1 and 2); determining the pattern of the primary work/school activity (decisions 3 to 8) and determining the pattern of secondary, fixed activities (decisions 9 to 13). In a next step, the location of each fixed activity episode will be predicted in the location module and finally the flexible activities, and their locations, will be scheduled in the flexible activities model component. The model chooses the end time of the morning sleep episode and the start time of the evening sleep episode. The primary work/school activity has maximally two episodes and a minimum duration of 1 hour per episode. The pattern is defined by decisions about the number of episodes, start time, duration(s) and interepisode time. Work/school activities with shorter duration are treated as a separate category of secondary fixed activities in the next step.

Compared with other activity-based models, ALBATROSS is unique in that rules as opposed to principles of utility maximization underlie the scheduling decisions. Furthermore, the rather detailed classification of activities and inclusion of a full set of space-time and scheduling constraints are distinctive features of the model compared with most other models.

Detailed information regarding the working of this model and the applied decision rules can be found in Arentze et al. [2003] or in Arentze and Timmermans [2005].

3. METHODOLOGY

The methodology to use an activity-based approach for estimating trip distances and vehicle emissions per trip motive consists of three successive steps. Focusing on the application in the Netherlands, this section will describe each of these steps briefly.

3.1 Activity-based modelling

In this study ALBATROSS was applied to predict activity travel schedules for the total Dutch population. The model is estimated on approximately 10,000 person-day activity-diaries collected in the period of 1997-2001 in a selection of regions and neighbourhoods in the Netherlands. First, a synthetic population, representing 30% of the households in the Netherlands, was created with iteratively proportional fitting (ITF) methods, using demographic and socio-economic geographical data from the Dutch population in base year conditions (2000) and attribute data of a sample of households from a National survey including approximately 67,000 households. Next, activity schedules were assigned to each individual within this synthetic population using the scheduling process in ALBATROSS as described before. The activity-based approach hereby offers information on different facets of the individual trip like the trip purpose, the trip duration and the characteristics of the trip performer. Of course, when concentrating on the impact of personal travel on the environment, only the trips that were made as a car driver need to be selected from the trip dataset, other transport modes can be ignored. After the prediction of these activity-travel schedules, detailed Origin-Destination (O/D) matrices, presenting the trips per trip motive, were extracted from the simulated activity-travel patterns.

3.2 Traffic assignment

The O/D-matrices per trip motive, predicted by the activity-based model Albatross, represent the trip behaviour for 30% of the Dutch population. In a second step, these O/D matrices were multiplied with the reversed sample fraction and assigned to a transportation network using a standard traffic assignment algorithm embedded in the software package TransCAD. TransCAD is a GIS platform designed for use by transportation professionals to store, display, manage, and analyze transportation data [Caliper, 2004]. Approximately 120,000 traffic links were present in the Dutch road network and the region was divided into 1,308 traffic zones.

After the traffic assignment procedure, detailed information was present about the activity-related traffic flows on the road links and total distances were calculated for each trip motive. The predicted results were compared with reported values from the Dutch National Travel Study (NTS) to validate the model results. The travel results from the 2000 survey were used for comparison. This survey includes trip diaries of more than 100,000 persons and results were reweighed to compensate for the under –and over-representation of certain groups, e.g. degree of urbanization, age, and journeys. Although the NTS uses trip diaries (as opposed to activity diaries), this travel survey has analogue survey characteristics as the activity-based survey (no holiday trips, no freight trips, no vehicle kilometers in other countries, no vehicle kilometers of foreigners), and is executed yearly to gain more insights into the travel behaviour of the Dutch population. More information about the NTS in the Netherlands can be found on the Dutch Road Safety Website [SWOV, 2000].

3.3 Emission calculation

Finally, in the last step of the methodology, the activity-related traffic flows on the different traffic links were converted into vehicle exhaust emissions based on pollutant-specific emission factors (g/km).

The most common emission factors result from the COPERT/MEET methodology [MEET, 1999]. According to this approach, vehicle type-specific emission functions combine the average speed data with specific emission parameters to estimate vehicle emissions for a certain time period and a certain region. This is a standard procedure for transport emission inventories in Europe although the uncertainty of the result is often underestimated [Int Panis et al. 2001; 2004]. Instead of working with separate emission factors per vehicle type, some regions also apply vehicle fleet emission factors per pollutant, taking into account the composition of the vehicle fleet and the characteristics of the road network. Of vehicle fleet emission factors are available, only information about the travelled distance is needed to calculate the resulting vehicle emissions.

In this study, we used the vehicle fleet emission factors for the Netherlands in base year conditions. The emission factors for carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_x), sulphur dioxide (SO_2) and particulate matter (PM) are presented in Table 1. To validate the emission results, emission values were compared with emission estimates from the Dutch Scientific Statistical Agency (CBS).

Table 1. Vehicle fleet emission factors for the Netherlands in the year 2000 (CBS, 2000)

	CO_2	CO	NO_x	SO_2	PM
Emission factor (g/km)	190	2.9	0.7	0.014	0.032

4. RESULTS

In this section, trip distances and emission results per trip motive are presented. When available, predicted results are compared with reported values to validate the model results.

4.1 Travelled distances

By aggregating the results from the traffic assignment procedure and extrapolating the values for a whole year, the total travelled distance during a whole year was calculated. In Table 2 the calculated value is presented next to the reported travelled distance value from the NTS, representing the total number of travelled kilometres by passenger car travel during the base year. The relative difference between both values is less than 10%.

Table 2. Total travelled distance by non-commercial vehicles in the Netherlands in the year 2000 [SWOV, 2000]

	Travelled distance (x 10^9 km)
Modelled travelled distance	93.3
Reported travelled distance	85.9
Relative difference (%)	8.6

After segregating the trips and the corresponding travelled distances according to trip motive, the annual number of vehicle kilometres per trip motive could be determined. To compare the predicted results with reported travel values, trips were classified according to the following seven NTS trip motives: work, school, shopping, leisure, social, service and other purposes (personal care, bring/get).

Figure 2 presents the travelled distances by trip motive for the activity-based method and the NTS method. Almost half of the total distance travelled is due to commuter purposes (more than 40 billion kilometres), followed by trips for social purposes (16 billion) and other purposes (12 billion). The activity-based approach predicts approximately the same amount of kilometres travelled for shopping and leisure trips (10 billion), and only a small amount of kilometres covered for school trips and services (1.5 billion).

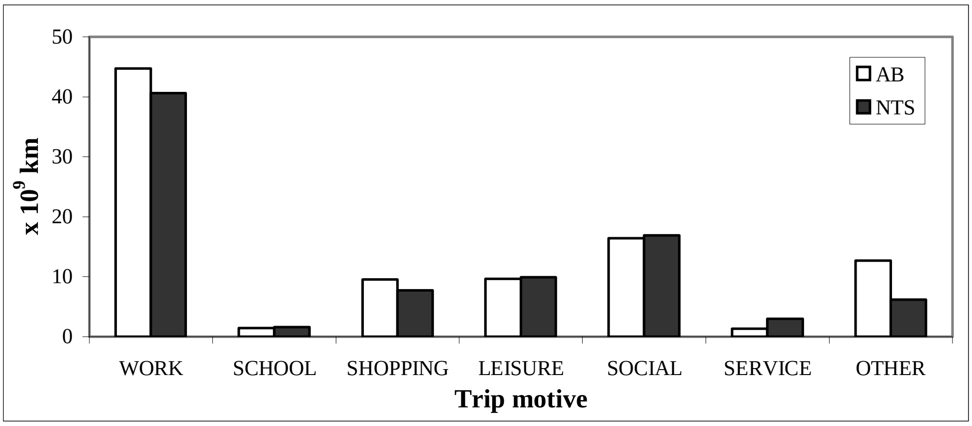

Figure 2. Total travelled distances per trip motive for passenger car trips in the year 2000: predicted activity-based (AB) values vs. reported NTS values [SWOV, 2000]

The results for the activity-based approach and the NTS approach seem to correspond well. The travelled distances for commuter trips, shopping trips and other trips are only slightly overestimated by the activity-based approach. On the other hand, school trips, leisure trips and trips with social purposes are slightly underestimated by the activity-based approach.

4.2 Vehicle emissions

Table 3 presents the total emission estimates per pollutant when the calculated travelled distance is multiplied with the corresponding fleet emission factor (see Table 1). These results were compared to the reported emission values for the year 2000 [CBS, 2000]. Model results for most pollutants seem to correspond well to the reported values. Relative differences between predicted and reported values fluctuate between approximately 2 and 9%.

Table 3. Calculation of total vehicle emissions for the year 2000, using vehicle fleet emission factors per pollutant [CBS, 2000]

	CO_2	CO	NO_x	SO_2	PM
Modelled emissions in 2000 ($x10^6$ kg)	17,729.06	270.60	65.32	1.31	2.99
Reported emissions in 2000 ($x10^6$ kg)	17,346.00	263.60	60.10	1.26	2.88
Relative difference (%)	2.21	2.66	8.69	3.97	3.82

As with the travelled distances, vehicle emissions can also be classified according to trip motive. By means of example, Figure 3 presents the contribution of different trips to the total amount of PM emissions. Calculations for other emissions yield similar results. As can be expected based on the travelled distance results, the largest amount of PM emissions is due to commuter trips: 47% of the total amount of PM emissions is attributed to work-related trips. Further, 17% of the emissions is caused by trips with social purposes, 20% is due to shopping and leisure trips and only a small percentage is caused by school trips and services-related trips. Trips with ‘other’ purposes still have a quite large contribution in the total PM emissions of approximately 13%.

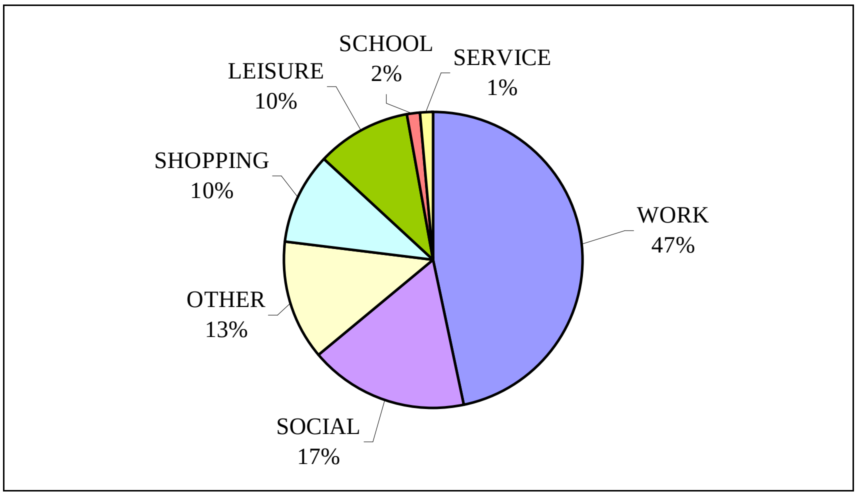

Figure 3. Activity-related PM emissions. Presentation of the relative contribution of different trip motives to the total amount of PM emissions

5. DISCUSSION AND CONCLUSION

In this paper we report on the use of an activity-based model to assess the activity-related distances and emission values for passenger car travel in the Netherlands. The activity-based model ALBATROSS was used to evaluate the travelled distance and the emissions of passenger car trips. First total travelled distance and total emissions were calculated and compared with officially reported values. Predictions for total travelled distances and total emissions of CO_2, CO, NO_x, SO_2 and PM differed not more than 8% from the reported values. Next, the trips (and the ensuing emissions) were classified according to trip motive to provide information about the contribution of different trips to traffic air pollution. By means of example, the results for the emissions of PM were presented in this paper. The commuter trips produced almost half of the total amount of PM emissions. Further, shopping and leisure trips together produced approximately 20% of the PM emissions, trips with a social purpose caused 17% of these emissions and school trips and service-related trips only caused a small percentage of the PM emissions. Calculations for other emissions yield similar results.

Of course, there are some qualifications to our research that need to be discussed. First, one can argue the validation method in itself. The predicted results from the activity-based emission modelling approach were compared with national travel and emission values from the Dutch Scientific Statistical Agency whose data originates from other surveys and model simulations. A good agreement between both values does not automatically indicate a good representation of the real situation, and only states the similarity between both models. Ideally, a validation method should comprise the use of measurements instead of simulation values, but the procedure of comparison with other models has been adopted by several authors for lack of a better alternative [e.g. Int Panis et al. 2006; Schrooten et al. 2008].
Next, the use of vehicle fleet emission factors can be a subject for discussion. The vehicle fleet emission factor takes into account the characteristics of the total vehicle fleet and general driving conditions, but takes no notice of local conditions. Since local road conditions and speed limits can significantly alter vehicle emissions [Int Panis et al. 2006; Beckx et al. 2007b], one should be careful when applying this approach for local policy questions. On the other hand the choice for a simplified emission calculation procedure with a constant emission factor also has some advantages. It is fast and provides us with a general evaluation of the impact of a policy measure on emissions. Nevertheless, future research should examine the use of more realistic emission factors to this extent. Leisure trips conducted in off-peak conditions will involve different emission factors than work trips occurring in the rush hour. Future research should therefore take into account trip departure times and locations to differentiate the use of emission factors for different trip motives.

The validation test in this research was 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. Since the activity-based approach allows for impact analysis of other, new, policy measures (see e.g. Beckx et al. 2005), the use of an activity-based travel model will certainly put a new perspective on the research of source-related policy measures. Moreover, due to the fact that this approach provides information about the activity-related emissions, policymakers will gain more insights into the impact of certain policy measures on different trips. Future studies will certainly comprise the use of an activity-based model for the evaluation of different policy measures on travel behaviour and vehicle emissions and will also take into account the use of other transport models, e.g. public transport, for different trip motives.

ACKNOWLEDGEMENTS

In this research data have been used from NTS (2000), which are available through the Dutch Scientific Statistical Agency.

REFERENCES

Arentze, T., Hofman, F., Timmermans, H., Reinduction of ALBATROSS Decision Rules with Pooled Activity-Travel Diary Data and an Extended Set of Land Use and Cost-Related Condition States, *Transportation Research Record*, 1831, 230-239, 2003.

Arentze, T., Timmermans, H., ALBATROSS: A Learning-Based Transportation Oriented Simulation System, *Transportation Research Part B,* 38, 613-633, 2000b.

Arentze, T., Timmermans, H., *ALBATROSS 2.0: A Learning-Based Transportation Oriented Simulation System,* European Institute of Retailing and Services Studies, Eindhoven, The Netherlands, 2005.

Beckx, C., Broekx, S., Janssens, D., Activity-based policies to reduce human exposure to traffic air pollution, *Proceedings of the 32nd International "Transportation Research Colloquium*, Antwerp, Belgium, Volume 7, 1955-1972, 2005.

Beckx, C., Int Panis, L., Vanhulsel, M., Wets, G. and Torfs, R., Gender-linked disparity in vehicle exhaust emissions? Results from an activity-based survey, *Highway and Urban Environment*, Morrison, G.M, and Rauch, S. (Springer, The Netherlands) 63-70, 2007a.

Beckx, C., Int Panis, L., De Vlieger, I., Wets, G., Influence of gear changing behaviour on fuel-use and vehicular exhaust emissions, *Highway and Urban Environment,* Morrison, G.M, and Rauch, S. (Springer, The Netherlands) 45-51, 2007b.

Bhat, C.R., Guo, J.Y., Srinivasan, S., Sivakumar, A., A comprehensive micro-simulator for daily activity-travel patterns, *Proceedings of the Conference on Progress in Activity-Based Models*, Maastricht, 2004.

Caliper Corporation, Travel Demand Modelling with TransCAD 4.7, Caliper Corporation, Newton, Massachusetts, 2004.

CBS, Emissies en Parkemissiefactoren (Emissions and Fleet Emission Factors), Analyses from the Dutch Scientific Statistical Agency, http://www.cbs.nl, 2000.

EEA, Environmental Indicators: Typology and Overview, Technological Report No 25, Copenhagen, 1999.

Ettema, D., Timmermans, H., Theories and models of activity patterns, *Activity-based approaches to travel analysis*, Ettema, D., and Timmermans, H. (Pergamon, Oxford), 1-36, 1997.

Int Panis L., De Nocker L., De Vlieger I., Torfs R., Trends and uncertainty in air pollution impacts and external costs of Belgian passenger car traffic, *International Journal Of Vehicle Design*, 27(1-4) 183-94, 2001.

Int Panis L., De Nocker L., Cornelis E., Torfs R., An uncertainty analysis of air pollution externalities from road transport in Belgium in 2010, *Science Of The Total Environment*, 334-35 287-98, 2004.

Int Panis, L., Broekx, S., Liu, R.H., Modelling instantaneous traffic emission and the influence of traffic speed limits, *Science of the Total Environment,* 371 (1-3) 270-285, 2006.

MEET, Methodology for calculating transport emissions and energy consumption, Transport Research, Fourth Framework Programme, Strategic Research, DG VII, ISBN 92-828-6785-4, 1999.

Pendyala, R.M., Kitamura, R., Kikuchi, A., Yamamoto, T. and Fujji, S., FAMOS: Florida activity Mobility simulator, *Proceedings of the 84th Annual Meeting of the Transportation Research Board,* Washington D.C., January 9-13, 2005.

Ruiter, E.R., Ben-Akiva, M., Disaggregate travel demand models for the San Francisco bay area, *Transportation Research Record,* 673, 121-128, 1978.

Schrooten, L., De Vlieger, I., Int Panis, L., Styns, K., Torfs, R., Inventory and forecasting of maritime emissions in the Belgian sea territory, an activity based emission model, *Atmospheric Environment,* 42(4), 667-676, 2008

Shiftan, Y., The Advantage of Activity-based Modelling for Air-quality Purposes: Theory vs Practice and Future Needs, *Innovation*, 13(1), 95-110, 2000.

Spear, B.D., New Approaches to Transport Forecasting Models, *Transportation*, 23, 215-240, 1996.

SWOV, Results from The National Travel Survey, The Netherlands, http://www.swov.nl/cognos/cgibin/ppdscgi.exe?toc=%2FEnglish%2FMobility, 2000.