APLLYING AN ACTIVITY-BASED MODELING FRAMEWORK TO THE EVALUATION OF VEHICLE EXHAUST EMISSIONS

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Abstract: This paper presents the first results of a research project that applies an activity-based travel demand model to the evaluation of vehicle exhaust emissions. More specifically, the activity-based model ALBATROSS, a fully operational computational process model, was used to predict activity schedules and trip matrices for personal vehicle travel in the Netherlands. By assigning the predicted matrices to a road network and converting the resulting traffic flows into emissions, good estimates were made of the vehicle emissions caused by personal vehicle travel. Considering the detailed level of activity and trip information present in the activity-based approach, these results are very promising for future research on the environmental impact of transportation control measures.

Keywords: activity-based modeling, ALBATROSS, TransCAD, vehicle emissions

1. INTRODUCTION

During the past few decades, traffic has become the dominant source of air pollution at several places. Advances in technology have played and will continue to play a role in managing the emissions associated with vehicular transport. However, the increasing number of vehicle miles traveled substantially offsets the emission reduction through advances in technology. Therefore, the use of other kinds of policies to reduce vehicle emissions, focusing more at the driving forces of this problem, should be studied. Unfortunately the benefits of these transportation control measures (TCM) are often unknown as there are limited data available to measure the travel effects of individual TCM strategies. The lacking of the interactions among individual and household travel decisions in response to TCM lay at the heart of the failings of conventional models to provide adequate measures of their potential impact (Recker, 1998). Questions that involve the linkages between a set of travel decisions and activities can not be examined through a traditional four-step transportation model. This kind of model focuses on individual trips where the spatial and temporal interrelationships between all trips are ignored. The inability of the four-step models to evaluate responses to TCM has prompted the development of an new approach to travel analysis, the activity-based approach.

The use of an activity-based travel model puts a new perspective on the research of policy measures offering a lot of advantages for air-quality purposes and policy evaluations (Recker, 1998; Shiftan, 2000). The major idea behind activity-based models 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. 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. This approach provides a more realistic forecast of the impact of policy measures. The advantages of activity-based modeling lie in its ability to give a better prediction of travelers' responses to TCM and, therefore, to provide a more accurate estimate of the changes in some important transportation variables. One of the main advantages of the activity-based modeling system is its ability to consider the secondary effects of TCM. Secondary effects are adjustments to the activity pattern that have to be made in response to the primary effect. For example, a public transport subsidy may make a commuter change his or her mode from drive alone to public transport; this is the primary effect of the TCM. Because, however, the person no longer drives to work, there can be no stop on the way back to do the shopping. Therefore, upon returning home, the person takes the car and drives to a nearby store. This is the secondary effect. In such cases, the advantages of TCM may be limited, and the reduction of the work auto trip is offset by a new shopping auto trip. Only an activity-based model can deal with these secondary effects.

In addition to the ability of activity-based models to evaluate traditional TCM such as subsidies for public transport or for transit, the activity-based approach also allows for impact analyses of alternative policy measures like:

- changing shop opening hours;
- introducing flexible work hours;
- promoting telecommuting;
- reducing the number of cars per household.

Activity-based models are able to evaluate the impact of these measures on travel behavior and transport, and due to this the impact on air-quality can be assessed and decisions can be made by the policymakers. Moreover, activity-based models are able to take into account several demographic changes to make accurate prognoses of travel behavior in time eg. changes in family size, number of driving licenses in the community,… providing a more realistic forecast of the impact of policy measures in the future.

Over the last years, several research teams have focused on building activity-based models of transport demand (e.g. Vovsha et al. 2003, Bhat et al. 2004, Arentze and Timmermans 2005 and Pendyala et al. 2005). Partial and fully operational activity-based micro simulation systems include the Micro-analytic Integrated Demographic Accounting System (MIDAS), the Activity-Mobility Simulator (AMOS), Prism Constrained Activity-Travel Simulator (PCATS), SIMAP, ALBATROSS, Florida's Activity Mobility Simulator (FAMOS) and other systems developed and applied to varying degrees in Portland, Oregon, San Francisco, and New York. But, although the potential advantage of an activity-based approach for air-quality purposes has been recognized from the beginning (e.g., Spear, 1994) and has been re-iterated more recently (e.g. Shiftan, 2000), to the best of our knowledge- models that have been developed along these lines are still scarce.

The remainder of this paper is organized as follows. Section two describes briefly the methodology to use an activity-based approach for the evaluation of vehicle emissions. In section three, this methodology will be illustrated for the Dutch situation and the first results of this case will be presented. Finally, the paper concludes and defines some topics for further research.

2. METHODOLOGY

The methodology to use an activity-based approach for estimating the emissions caused by personal vehicle travel in a certain region consists of three successive steps. This section will describe each of these steps briefly.

2.1 Activity-based modeling

The first step in the methodology involves the application of an activity-based travel demand model. Based on a very detailed data set including activity and trip information of a large population sample, the activity-based model is able to predict activity schedules for a whole population.

After the prediction of activity schedules, detailed origin-destination (O/D) matrices can be extracted from the simulated activity-travel patterns. This procedure provides detailed information about the travel behavior of the individuals within the modeled population. 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 vehicle travel, only the trips that were made as a car driver have to be selected from the trip dataset, other transport modes can be ignored.

2.2 Traffic assignment

In a second step, the O/D matrices that are predicted by the activity-based model will be assigned to a transportation network using a traffic assignment algorithm. According to data availability, different traffic assignment algorithms can be used (all or nothing, shortest route, fastest route, …) and, of course, different results will be obtained. The results of this assignment will usually consist of hourly traffic flows per hour and per link, but, also data about hourly vehicle speeds can be obtained if more advanced assignment algorithms are used.

The accuracy of the assignment results will not only depend on the applied assignment algorithm, but also on the available link information and on the number of traffic zones that are used.

2.3 Emission calculation

Finally, in the last step of the proposed methodology, the traffic flows on the different traffic links are converted into vehicle exhaust emissions based on emission factors (in g/km). The most common emission factors result from the Copert/MEET methodology (MEET, 1999). This methodology assumes that vehicle data and average speed data are available for the year that is modeled. Specific emission functions for every vehicle type will combine the average speed data with vehicle specific emission parameters to estimate vehicle emissions for a certain time period and for a certain region.

In some regions, in stead of working with separate emission factors per vehicle type, vehicle park emission factors are also present, taking into account the composition of the whole vehicle park (or only the personal vehicles) and the characteristics of the road network. In that case, only information about the traveled distance is traveled is needed to be able to calculate the produced vehicle emissions.

3. RESULTS

The developed methodology was applied on the assessment of vehicle emissions in the Netherlands. This section presents some results from the three successive steps in the methodology for the vehicle emission calculation for this country.

3.1 Activity-based modeling with Albatross

To illustrate the activity-based approach for the evaluation of vehicle emissions, the activity-based model Albatross, A Learning-Based Transportation Oriented Simulation System (Arentze and Timmermans, 2000), was applied for the Dutch situation. Albatross is a computational process model that relies on a set of decision rules to predict activity-travel patterns. It was developed for the Dutch Ministry of Transportation, Public Works and Water Management as a transport demand model for policy impact analysis and is able to predict which activities are conducted, when, where, for how long, with whom, and the transport mode involved. The next paragraph gives a brief overview of the scheduling process in Albatross. More information about the working of this model and other computational process models can be found in Arentze and Timmermans (2000, 2005).

Rules in Albatross are typically extracted from activity diary data. The activity scheduling agent of Albatross is the core of the system which controls the scheduling processes in terms of a sequence of steps. These steps are based on an assumed sequential execution of decision tables to predict activity-travel patterns. The first step involves for each person decisions about which activities to select, with whom the activity is conducted and the duration of the activity. The order in which (the non-work) activities are evaluated is pre-defined as: daily shopping, services, non-daily shopping, social and leisure activities. The assignment of a scheduling position to each selected activity is the result of the next two steps. After a start time interval is selected for an activity, trip chaining decisions determine for each activity whether the activity has to be connected with a previous and/or next activity. Those trip chaining decisions are not only important for timing activities but also for organizing trips into tours. The next steps involve the choice of transport mode for work, the choice of transport mode for other purposes and the choice of location. Possible interactions between mode and location choices are taken into account by using location information as conditions of mode selection rules. Each decision in the Albatross system extracted from activity travel diary data using a Chi-squared based technique CHAID. CHAID is a widely-used decision-tree induction method.

For this study, Albatross version 3.0 was used to predict schedules for 30% of the Dutch population. First a the synthetic population was created using iteratively proportional fitting methods, representing 30% of the households in the Netherlands in the year 2000. A synthetic population of 30% was, at that moment, the maximum size that could be used by the model. Next, activity schedules were predicted for each individual within this synthetic population using decision-tree induction methods as described above. For a synthetic population of 30% the number of household cases in the Netherlands amounts approximately 2 million.

Finally, origin-destination (O/D) matrices were extracted from the predicted activity schedules. As we focused on vehicle trips in this study, only O/D-matrices from trips made as a car driver were selected for further analysis. To account for differences in travel behavior within one week, trip matrices were analyzed for three different days in a week: a weekday, a Saturday and a Sunday. Further, trips were divided into six time periods a day (before 10 am, between 10 am and 12 am, between 12 pm and 14 pm, between 14 pm and 16 pm, between 16 pm and 18 pm, and trips after 18 pm) and 1308 zones were used as origin or destination.

3.2 Traffic assignment

The O/D-matrices, predicted by the activity-based model Albatross, represent the trip behavior for 30% of the Dutch population during different times per day and on different days of the week. Before assigning these trips to a road network, the matrices were extrapolated to represent the travel behavior of the whole Dutch population. Next, these trip matrices were assigned to the Dutch road network by using an ‘all-or-nothing’ traffic assignment algorithm embedded in the software package TransCAD. A more dynamic assignment, in stead of this static ‘all-or-nothing’ assignment, was not (yet) possible since no information about road capacity was available.

Approximately 120000 traffic links were present in the Dutch road network and the region was divided into 1308 traffic zones, corresponding to the origin and destination zones used in the Albatross model. Figure 1 presents the study area with its 1308 traffic zones. The average area size of a traffic zone is approximately 20 km².

Figure 1. Presentation of the 1308 traffic zones in the study area.

After the traffic assignment procedure, detailed information is present about the traffic flows on the road links during different times of a day an on different days a week (weekday, Saturday, Sunday). By aggregating these results and extrapolating the values for a whole year, the total travel distance during the modeled year (2000) can be calculated. In Table 1 this calculated value is presented next to the reported value on this topic. The reported value originates from Dutch travel statistics and represents the total number of traveled kilometers by personal vehicle travel during the year 2000.

Table 1. Total travel distance by personal vehicle travel in the Netherlands ([a]CBS, 2000)

	Travel distance (x 10^9 km)
Modeled travel distance	93.3
Reported travel distance[a]	89.1
Relative difference (%)	4.6 %

Since geographical information is also present about the different traffic links and their traffic flows, the result of the traffic assignment can also be visualized on map. Figure 2 shows the total traffic flows on the different traffic links during one year.

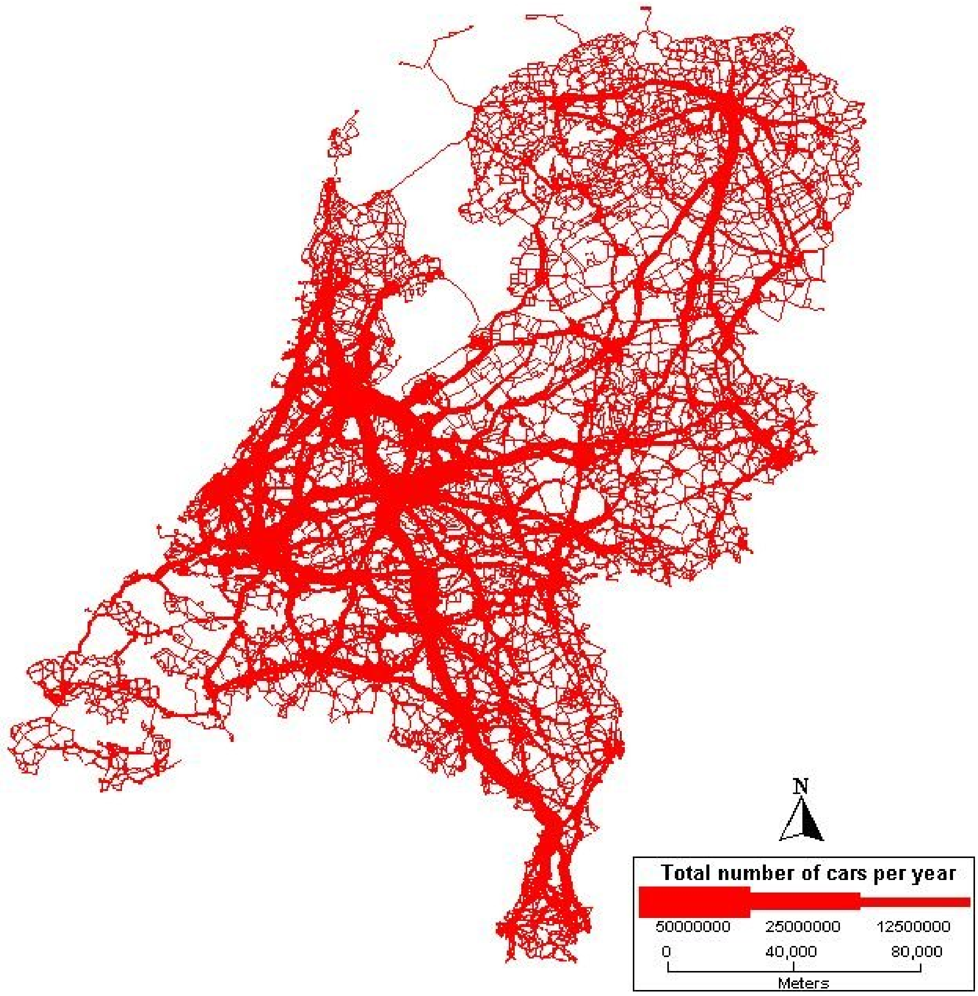

Figure 2. Geographical presentation of the modeled traffic flows during the year 2000.

When aiming hourly traffic flows (and emission estimates), the trips predicted by the Albatross model need to be split up since trips in Albatross are only present in six time periods. To perform this action properly, the results from another travel behavior study, "*onderzoek verplaatsingsgedrag"*, were used, taking into account the relative frequency of trips during the different time periods (CBS, 2000). When applying the calculated relative frequencies from this travel study on the trips modeled by Albatross, hourly traffic flow data can be presented. Figure 3 shows e.g. the traveled distance during an average weekday that was calculated with Albatross.

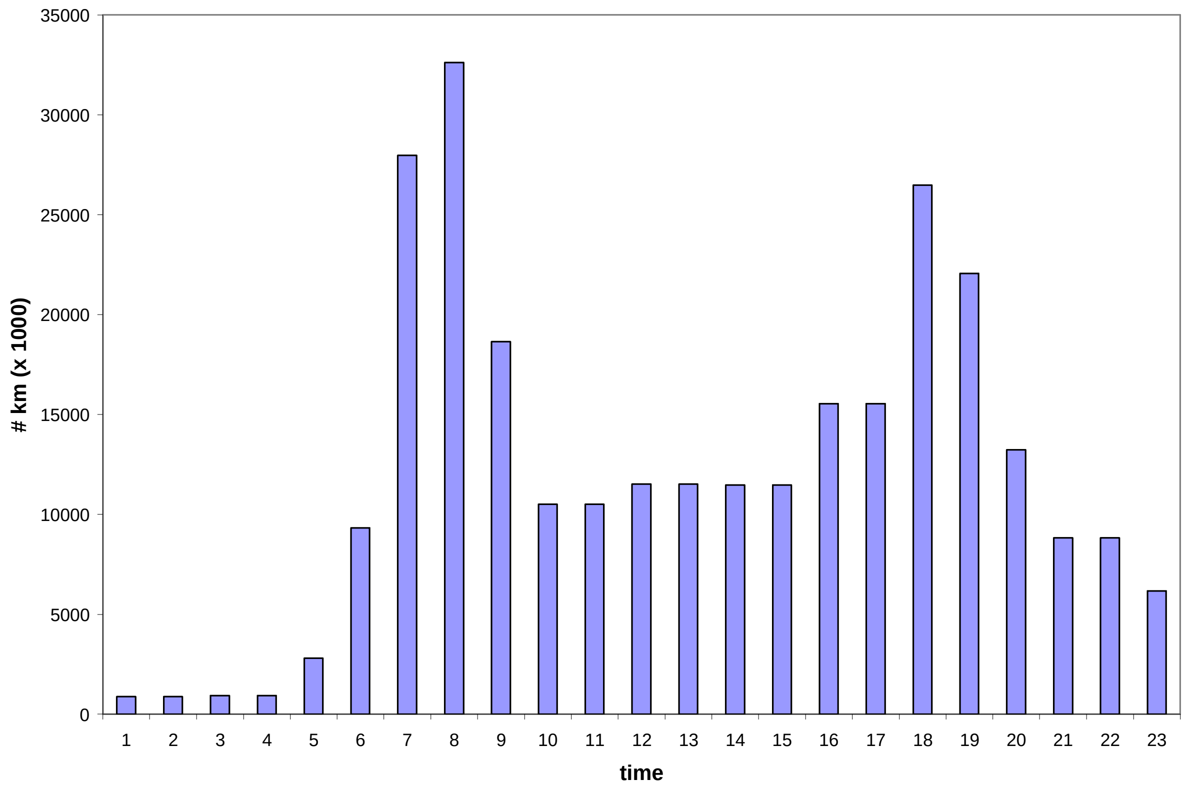

Figure 3. Hourly distance traveled during an average weekday

3.3 Emission calculation

Based on the traffic flows that result from the assignment procedure emission estimates can be made for the personal vehicle travel in the Netherlands. Total emission values, hourly emissions and geographically spread emissions can all be calculated.

In this study, vehicle emissions were calculated by two different methods. The first one uses one 'total' emission factor per pollutant to calculate the emissions for the whole vehicle park (see 'total' in Table 2). This emission factor takes into account the composition of the personal vehicle park in the year 2000 and the characteristics of the road network. The second method works with different park emissions factors per pollutant according to the type of traffic link where traffic flows occur (Table 2). According to this second method three different emission factor are present, for urban links, rural links and highways, and the traveled distance needs to be multiplied, per link, with the appropriate emission factor.

The results of the emission calculations for method 1 and method 2 are presented in Table 3 en Table 4 respectively. Both tables also present the reported emission values for the same model year.

Table 2. Vehicle park emission factors (CBS, 2000)

	CO_2 (g/km)	CO (g/km)	NO_x (g/km)	SO_2 (g/km)	PM10 (g/km)
Total (1)	190	2.9	0.7	0.014	0.032
Urban (2)	257	7.3	0.8	0.016	0.044
Rural (2)	162	1.9	0.5	0.010	0.022
Highway (2)	182	1.6	0.7	0.015	0.034

Table 3. Calculation of total vehicle emissions for the year 2000, using 1 emission factor per pollutant ([a]CBS, 2000)

	CO_2	CO	NO_x	SO_2	PM10
Modeled emissions in 2000 ($x10^6$ kg)	17729.06	270.60	65.32	1.31	2.09
Reported emissions in 2000[a] ($x10^6$ kg)	17346.00	263.60	60.10	1.26	2.88
Relative difference (%)	2.21	2.66	8.69	3.97	-27.43

Table 4. Calculation of total vehicle emissions for the year 2000, using 3 emission factors per pollutant ([a]CBS, 2000)

	CO_2	CO	NO_x	SO_2	PM10
Modeled emissions in 2000 ($x10^6$ kg)	18498.65	339.73	60.18	1.22	2.99
Reported emissions in 2000[a] ($x10^6$ kg)	17346.00	263.60	60.10	1.26	2.88
Relative difference (%)	6.65	28.88	0.13	-3.17	3.82

Table 3 presents the emission estimates when the calculated traveled distance is multiplied by only one park emission factor. These results were compared to the reported emission values for the year 2000. Model results for most pollutants seem to correspond well to the reported values. Except for the PM10 value, the relative differences between modeled and reported values are less than 10%. In Table 4 the emission estimates from the second method are presented. In this case, the modeled results for CO seem to differ from the reported value. For the rest of the pollutants the predicted results correspond very well with the reported emission values.

Differences between the values in Table 3 en Table 4 can be explained by the traffic assignment procedure. Since no capacity information was present in the road network data file, the assignment procedure was limited to an “all-or-nothing” assignment. If the results from this assignment differs strongly from reality, e.g. more kilometers are modeled on rural links than traveled in reality, than this will have its implications for the emission estimates.

4. CONCLUSION

In this study we demonstrated the ability of an activity-based model to make accurate predictions of the travel behavior of people. More specifically, modeled travel distance and emission estimates for the situation in the Netherlands were compared with reported values on these topics and seemed to correspond well with these estimates. These results are very promising for further research since the activity-based approach offers more possibilities for policy impact analysis than the traditional travel demand model.

Future research will not only involve impact analyses of different transportation control measures, but will also focus on further enhancements of the traffic assignment and emission calculation procedure to improve the vehicle exhaust assessments. Topics in this future research include the assignment of intra-zonal trips (not included in this study) and the calculation of cold start emissions by taking into account the time between two successive vehicle trips.

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