ACTIVITY-BASED POLICIES TO REDUCE HUMAN EXPOSURE TO TRAFFIC AIR POLLUTION

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Samenvatting

Activiteiten gebaseerde maatregelen voor het reduceren van de blootstelling aan verkeerspolluenten

De laatste jaren vindt er een trend plaats naar het gebruik van activiteiten gebaseerde transportmodellen om het verplaatsingsgedrag van mensen te modelleren. Activiteiten gebaseerde modellen beschouwen de verplaatsingsvraag als een afgeleide van de activiteiten die individuen en huishoudens wensen uit te voeren. Gecombineerd met een milieumodule heeft het gebruik van deze modellen belangrijke voordelen naar luchtkwaliteits- en blootstellingsanalyses toe, evenals voor de evaluatie van de impact van beleidsmaatregelen. Het onvermogen van de traditionele vierstapsmodellen om dergelijke beleidsmaatregelen te evalueren en om noodzakelijke data voor luchtkwaliteitsanalyses te leveren, leidde dan ook tot de ontwikkeling van een activiteiten gebaseerde aanpak voor luchtkwaliteitsdoeleinden. Deze paper illustreert het gebruik van activiteiten gebaseerde modellen voor het bepalen van de blootstelling aan verkeerspolluenten en legt uit hoe dergelijke aanpak voordelen oplevert voor beleidsmakers, ook in het kader van een duurzame mobiliteit.

Summary

Activity-based policies to reduce human exposure to traffic air pollution

For the last decade, activity-based transportation models have certainly set the standard for modelling travel demand. Activity-based modelling treats travel demand as derived from the activities that individuals and households need or wish to perform. In combination with the use of environmental models this approach has important advantages for air quality and exposure analyses and for the evaluation of air-quality benefits from policy measures. The inability of the traditional four-step models to evaluate responses to transportation control measures and to provide data on all the variables required for air-quality analysis has prompted the development of an activity-based approach for air quality purposes. This paper reports on the use of activity-based models for the assessment of human exposure to traffic air pollution and presents the advantages of this approach for policymakers, even within the scope of sustainable mobility.

1. Introduction

An efficient transport system is a vital requirement for economic development and provides personal mobility for activities such as work, education and leisure that are key ingredients of modern life. But transport also contributes significantly to several environmental and health problems, like climate change, acidification and local air pollution. Numerous studies have indicated that exposure to air pollution increases risks of developing cancer, respiratory and allergic diseases, and aggravates the condition of people suffering from respiratory or heart diseases (Torfs, 2004). Quantifying the impact of traffic air pollution on the public's health has therefore become an increasingly critical component in policy discussion.

The last decades, several transportation control measures (TCM) have been defined to manage both emissions and exposure associated with vehicular transport. Unfortunately, the total vehicle miles travelled and the number of trips made increased drastically, substantially offsetting the emission reduction through advances in technology. Due to this fact one should consider the use of other policies aimed at encouraging efficient trip chaining and scheduling of activities. Such policy measures could have the potential to lead to significant reductions in vehicle emissions but these assumptions need conformation. 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 use of an activity-based model on the contrary will put a new perspective on the research of alternative 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 (Ettema and Timmermans, 1997).

The remainder of this paper is organized as follows. Section two gives a brief introduction towards activity-based modelling. The use of activity-based models for air quality purposes and a description of activity-based policies are explained into detail in section three. Next, the potential contribution of this research to the sustainable mobility concept is described briefly. Finally, the paper concludes and defines some topics for future research.

2. Activity-based modelling

Activity-based transportation models have certainly set the standard for the last decade of modelling travel demand. This section presents briefly the historic evolution towards activity-based modelling and describes the most important features of the activity-based approach.

2.1 Historic evolution

Modelling traffic patterns has always been a major area of concern in transportation 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 were used by transportation planners. These models were necessary to predict travel demand on the long run and to support investment decisions in new road infrastructure which originated from this increased level of car use. In these days, travel was assumed to be the result of four subsequent decisions which were modelled separately. Those models are also referred to within transportation literature as Four-Step trip-based models (Ruiter and Ben-Akiva, 1978). A lot of these aggregate Four-Step models failed to make accurate predictions. The major drawback clearly is the focus on individual trips, where the spatial and temporal interrelationships between all 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.

From the mid seventies onwards the original Four-Step models were replaced by tour-based models where multinomial logit techniques and more sophisticated techniques such as the nested logit and probit models formed the core of transportation modelling practice (Daly *et al*, 1983). In the tour-based model, trips are explicitly connected in chains that start and end at the same home or work base. By means of this property, the lack of the spatial interrelationship, which was so apparent in the Four-Step trip based models, is dealt with. Nevertheless in these models, travel still has an isolated existence and the question why people undertake trips is completely neglected. This is where activity-based transportation models came into play.

2.2 The activity-based approach

The contributions of Hägerstrand (1970), Chapin (1977) and Fried *et al*. (1977) are the undisputed intellectual roots of activity analysis. Hägerstrand suggested the time-geographic approach characterizing a list of constraints on activity participation. Chapin has identified patterns of behaviour across time and space. Fried, Havens and Thall have dealt with the social structure and the question of why people participate in activities. These contributions came together in a study of Jones *et al*. (1983), where activities and travel behaviour were integrated. This was the first initial attempt to model complex travel behaviour.

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 (Ettema and Timmermans, 1997). Travel is merely seen as just one of the attributes. Moreover, decisions with respect to travel are driven by a collection of activities that form an agenda for participation. Travel should therefore be modelled within the context of the entire agenda, or in other words, as a component of an activity scheduling decision. Activity-based approaches aim at predicting *which* activities are conducted, *where*, *when*, for *how long*, *with whom* and the *transport mode* involved.

In order to summarize the most important features of activity-based modelling, we would like to cite the work of McNally (2000), who has nicely listed 5 themes which characterize the activity-based modelling framework:

(i) Travel is derived from the demand for activity participation;

(ii) sequences or patterns of behaviour, and not individual trips are the relevant unit of analysis:

(iii) household and other social structures influence travel and activity behaviour;

(iv) spatial, temporal, transportation and interpersonal interdependencies constrain activity/travel behaviour;

(v) activity-based approaches reflect the scheduling of activities in time and space.

3. Methodology

This section describes the methodology for the use of activity-based models in air quality research and shows how the assessment of important variables for air-quality analysis can be improved by the use of activity-based models. Furthermore this section presents the advantages of an activity-based approach for policymakers who wish to reduce the impact of traffic air pollution.

3.1 DPSIR framework

The methodology used in this research is structured according to an integrated assessment framework known as the DPSIR framework where DPSIR stands for Driving forces, Pressure, State, Impact and Response (figure 1). The DPSIR framework was built on a model from the Organisation for Economic Co-operation and Development (OECD, 1993), and a few years later adopted by the European Environmental Agency for environmental reporting purposes (EEA, 1999). This model structures the description of the environmental problems by formalising the relationships between various sectors of human activity and the environment as causal chains of links (figure 1).

The DPSIR approach takes into account the connections between the causes of environmental problems, their impacts, and the societal responses to which they give rise. This integrated assessment approach brings together relevant information about causes, impacts and solutions in order to structure the environmental problem and present efficient policy measures of a certain issue.

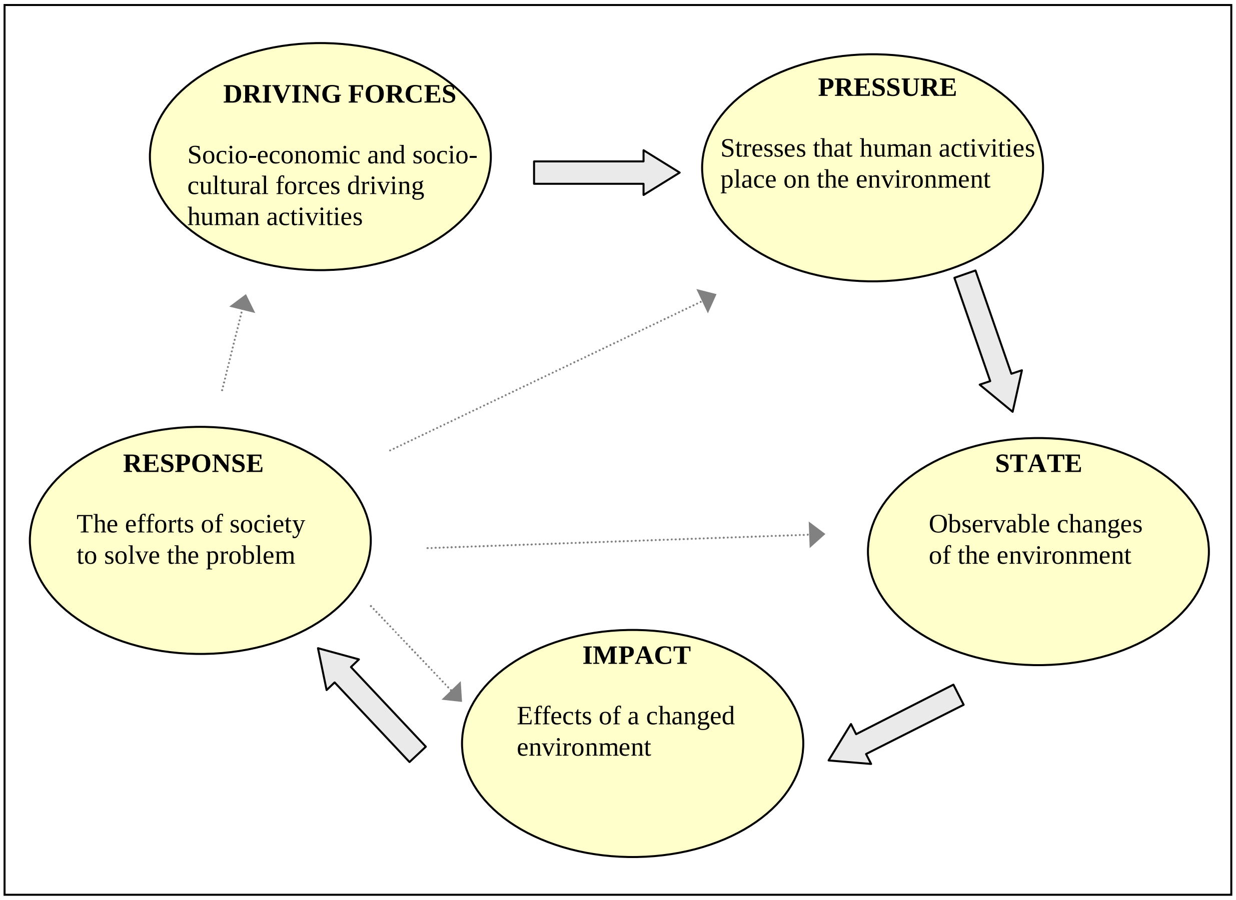

FIGURE 1. The Driving force-Pressure-State-Impact-Response model

The DPSIR framework can be applied to studies of the present as well as of possible future situations. In order to structure the problem of human exposure to traffic air pollution an adapted DPSIR framework was developed. Figure 2 illustrates the DPSIR framework for human exposure to traffic air pollution.

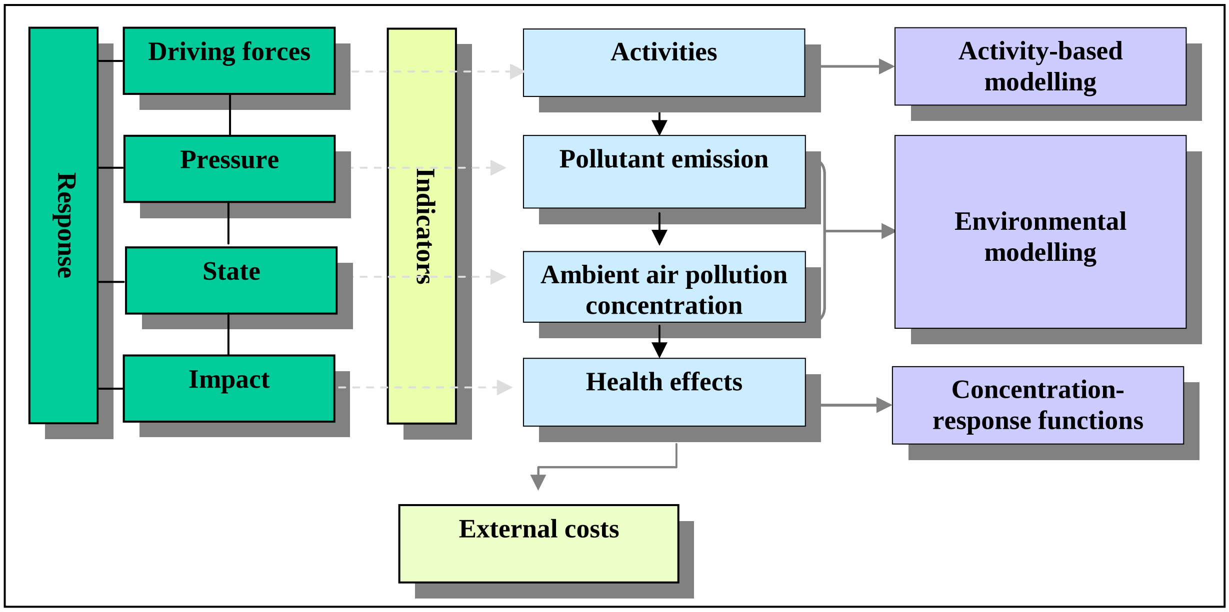

FIGURE 2. DPSIR framework for the human exposure to traffic air pollution

Figure 2 can be explained as follows: the *driving forces* related to the problem of traffic air pollution are the underlying activities that people want or have to perform. People go to work or to school, they go shopping, have an active social life… In order to perform all these activities, travel is a necessary consequence. Models providing predictions of the travel demand and trips through an analysis of activities are activity-based models. The environmental *pressures* ensuing from these driving forces consist of the emissions caused by the different transport modes. Vehicle exhaust emissions contain carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM). The amount of pollutants depends on different vehicle and driving characteristics, and is determined by the use of emission models. Next, the emitted pollutants are dispersed in the surroundings leading to a degraded *state* of the environment. Dispersion models aim at predicting the eventual ambient concentration of traffic air pollutants depending on the meteorological situation and the chemical transformation of pollutants. Finally, the exposure of people to these concentrations has an *impact* on human health (concentration-response functions) and makes the society carry out a *response* through various actions. Through valuation rules this approach will allow for monetization of environmental damage costs (*external costs*) from traffic air pollution for human exposure (Int Panis *et al*, 2004).

3.2 Activity-based modelling for air quality purposes

There are many transportation variables that affect emissions of traffic air pollutants. Cambridge Systematics (1997) provides a table prioritizing the transportation data desired for emission modelling. The following variables have been identified as the most important for this type of analysis:

- VMT (vehicle miles of travel);
- travel by mode and occupancy rates for auto modes;
- percentage of cold/hot starts;
- speed/acceleration/driving profile;
- travel by time of day and time/location of starts;
- travel by vehicle class and model;
- travel by facility type.

The accuracy of the emissions and air-quality estimates can be no better than the underlying transportation information (Int Panis *et al*, 2004). Due to the richer set of concepts which are involved in activity-based transportation models the estimate of each of the transportation variables listed above can be improved by using an activity-based approach (Shiftan, 2000). Vehicle energy use and emissions depend not only on distance and the driving speed, but also on the number of trips, the time between them, and whether the vehicle was warmed up or not when started (Recker, 1998). The activity-based prediction of trips as parts of a tour can identify whether a trip is a cold or a hot start. Furthermore, an activity-based model predicts which activities are conducted, where, when, for how long, with whom and the transport mode involved, giving accurate information about the other transportation variables in the list like VMT, travel by mode and occupancy rate, and travel by time of day.

Activity-based transportation models not only provide accurate information on the sources of traffic pollution but also on the location of the pollution receptors. In addition to the advantages on emissions and air-quality estimates, the use of activity-based models also offers opportunities to improve the exposure assessment to traffic air pollution.

Thus, in combination with the use of environmental models the activity-based approach is able to integrate data on traffic activity, pollutant emission and dispersion, and travel behaviour to derive individual- or group-level exposure measures to traffic air pollution. This integrated method corresponds to the DPSIR approach as illustrated in figure 2. Due to the use of activity-based models the problem related to the exposure to traffic air pollution can be split into the different compartments of the DPSIR framework providing a thorough structured analysis of the problem.

3.3 Air quality impacts of activity-based policies

During the past few decades, traffic has become the dominant source of air pollution in larger cities. A lot of transportation control measures (TCM) have yet been defined to counter the rise in vehicle emissions and energy consumption due to increased travel. Advances in technology have played and will continue to play a role in better managing both energy consumption and emissions associated with vehicular transport. Both environmental policy (esp. at EU-level) as well as environmental assessments have focused on technological measures (Int Panis *et al*, 2003).

However, the total vehicle miles travelled and the number of trips increased drastically lately, substantially offsetting the emission reduction through advances in technology. Other policies, aimed at encouraging efficient trip chaining and scheduling of activities, could have the potential to lead to significant reductions in vehicle emissions. Unfortunately the value of these TCM strategies is often unknown as there are limited data available to measure the travel effects of individual TCM strategies and the models are inadequate for forecasting changes in travel behaviour that result from these strategies. The nature of the interactions among the collection of individual and household travel decisions in response to TCM lay at the heart of the failings of conventional models and data to provide adequate measures of their potential impact (Recker, 1998). The inability of the four-step models to evaluate responses to TCM and to provide data on all the variables required for air-quality analysis has prompted the development of an activity-based approach for air-quality purposes.

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 modelling lie in its ability to give a better prediction of travellers' responses to TCM and, therefore, to provide a more accurate estimate of the changes in the important transportation variables identified in the previous section from the implementation of TCM. One of the main advantages of the activity-based modelling 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 to evaluate traditional TCM such as subsidies for public transport or for transit and adjustments to the road infrastructure, specific activity-based policy measures also include actions like:

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

Activity-based modelling evaluates the impact of these measures on travel behaviour and transport, and due to this the impact on air-quality can be modelled 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 behaviour 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.

4. Link to sustainable mobility?

Although the list of definitions for sustainability and Sustainable Development is long, the most widely used definition of Sustainable Development is probably the one given by the World Commission on Environment and Developent (WCED):

> *Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs (WCED, 1987).*

Sustainable Development was proclaimed a guiding political concept at the United Nations' World Summit on Environment and Development in 1992. The European Union has since then adopted strategies to implement the concept in their policies. For some years now, sustainable mobility has become an explicit aim of transport planning and policy making at local, national and international levels. Strategies for sustainable mobility have been adopted, which emphasise the integration of environmental and social goals with economic ones (figure 3).

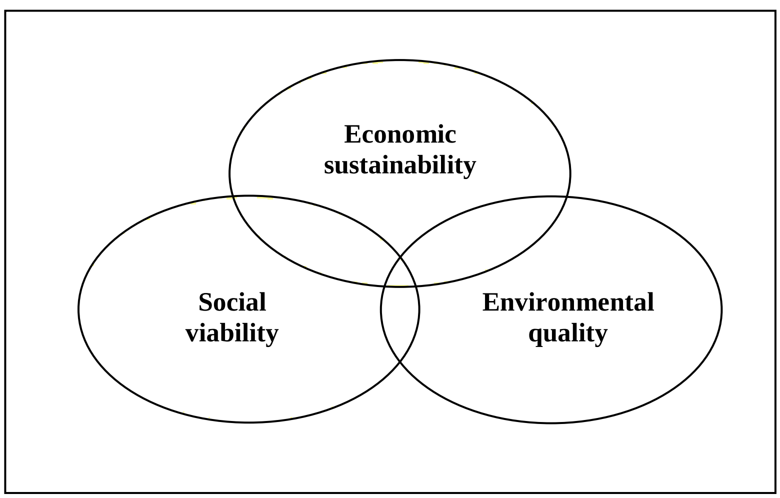

FIGURE 3. The integration of environmental, social and economic goals in the concept of sustainable mobility.

The demand for transport services is expected to grow considerably as incomes rise, the trend toward urbanization continues and as the process of globalisation moves forward with expected increases in world trade and personal travel (United Nations, Economic and Social Council, 2001). In order to meet this rising demand and because governments cannot afford to allow transport constraints to have a negative impact on the future competitiveness of their products, considerable future long-term investments are indispensable. In order to better guide and substantiate the decisions of transportation planners, the use of traffic and transportation models has been advocated by governments and by research communities.

The DPSIR approach adopted in this research reflects the multidimensional approach inherent in the concept of sustainable mobility. It integrates data on traffic activity, pollutant dispersion and travel behaviour, to derive individual- or group-level exposure measures to traffic air pollution. Due to the combination of activity-based models with environmental models the evaluation of policy measures to reduce the impact of traffic air pollution can be performed on different levels in the framework. Even the impact of policy measures concerning the first step in the DPSIR model, the driving forces, can be evaluated through the activity-based approach. This methodology will allow for an accurate forecast of the impact of different kinds of policy measures and will contribute to the improvement of a sustainable mobility.

5. Conclusions and further research

This paper reports on the use of activity-based models for the assessment of human exposure to traffic air pollution. Due to the richer set of concepts which are involved in activity-based transportation models this approach has important advantages for air quality and exposure analyses since it integrates data on traffic activity, pollutant emission, pollutant dispersion and travel behaviour. The use of activity-based models in combination with environmental modelling will offer an improved evaluation of policy measures to reduce human exposure to traffic air pollution and will allow for an accurate forecasting of the policy's impact.

Future research consists of turning the concept of activity-based modelling for air-quality purposes into reality. An activity-based model will be integrated with an emission and a dispersion model to provide accurate information on the sources of traffic pollution and on the location of the pollution receptors. First, concentrations of traffic air pollutants will be geographically determined in a certain region. Next, the human exposure to traffic air pollution can be assessed by combining the concentration maps with the people's presence maps in a geographic information system. By applying concentration-response functions and valuation rules this approach will allow for monetization of environmental damage costs from traffic air pollution for human exposure. An evaluation of a wide range of policy measures will be possible and will offer important advantages for policymakers.

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