ASSESSMENT OF TRAFFIC CONTROL MEASURES FOR THE REDUCTION OF POLLUTANT EMISSIONS USING TRAFFIC FLOW SIMULATION

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1. INTRODUCTION

The emissions caused by motorised traffic are of growing concern within transportation planning, and local authorities in Germany are now entitled to restrict traffic in areas where concentrations of certain pollutants exceed legally defined standards. The possibility of such traffic restrictions leads to a demand for control strategies that can be applied in such situations, and for tools that can be used to develop and assess these strategies. In our project we try to use the existing signal control infrastructure in order to relieve the emission situation of a critical area, that is an area defined as especially sensitive to air pollution. Signal control can be used on the one hand side to reduce the traffic volume flowing into the area, and on the other hand side to control the remaining traffic in a way to minimise emissions.

Microscopic traffic simulation is an established tool for the development and assessment of signal control strategies, in particular traffic actuated signal control. Microscopic modelling is necessary to cover measures that are oriented on traffic situations at the level of single vehicles, e.g. public transport priority at signal controlled junctions. For the development of emission-minimal control strategies it would be helpful, if the existing microscopic traffic simulation tools provided also a computation of the emissions at the corresponding level of resolution in space and time. Such models for fuel consumption and pollutant emissions have been developed in the past (e.g. Benz 1984), but they depend on large amount of data for every type of vehicle to be simulated, typically they need an engine map for each pollutant component. This information is not available for the whole fleet of vehicles or at least for a representative subset of the fleet. On the other hand side, representative emission factors have been determined with high expenditure and published by the German Umweltbundesamt (i.e. the federal office for the environment), that can be used in principle to compute emissions from simulated traffic data (Hassel et. al. 1994). However, these emission data are published in a high degree of aggregation, so that a computation of emissions for a single trip of a single car is not possible, and the calculation procedure proposed by the Umweltbundesamt for the usage with the emission factors (Hoepfner et. al. 1995) is not sensitive enough for the assessment of measures whose impacts do not exceed

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certain thresholds. For example, the positive effects of a slightly improved signal timing at a junction normally will not be reflected by the standard assessment procedure proposed for the emission factors.

In our project we had an practical and a methodical objective: On the practical side some hints for developing emission-minimal traffic control in critical areas were to be found. In order to do this, the methodical objective was to develop a tool for the development and assessment of signal control strategies by combining microscopic traffic flow simulation and representatively determined emission factors. As a concrete example an area in the city of Mannheim (a German city with about 300.000 inhabitants) was selected and modelled in the simulation system.

2. AVAILABLE EMISSION DATA

In October 1995 the Umweltbundesamt published the Manual for Emission Factors for Road Traffic (UBA 1995). It contains fuel consumption and pollutant emission per vehicle-kilometre for a catalogue of so called traffic situations. The vehicle fleet is divided into so called vehicle layers, each layer representing a group of vehicles with comparable emission characteristics, e.g. engine type, cubic capacity and type of exhaust gas purification. The data is available on CR-ROM, together with a computer program, that implements the emission calculation procedure proposed by Hoepfner et. al. (1995).

In order to judge the suitability of these emission factors for a microscopic assessment of traffic flows, the method must be studied by which the emission factors have been determined. The first step was to develop the catalogue of not too many traffic situations that covers all common situations in urban and interurban road traffic. Therefor a great many of test drives were performed, covering several thousand kilometres in varying situations. These test drives were analysed and each drive was described by a set of thirteen statistical parameters, e.g. mean speed, stand still time, distribution of acceleration etc. Based on this statistical description cluster analysis lead to a set of ten typical driving patterns. The complete procedure for the determination of the driving patterns is described in Bartelt et. al. (1994).

The emission factors these ten typical driving patterns were determined by measuring cars on the test bench. For each vehicle layer representative cars were chosen. The emission for the driving patterns was not measured directly, but all cars were measured while driving four standardised driving cycles. These driving cycles are defined in a way that they cover the whole range of possible states of the engine. The result of the test bench measurements was a function for each layer that maps instantaneous speed and acceleration to the emission of the different pollutants. These emission functions would be an ideal basis for the computation of emissions for microscopic simulated traffic flows, but unfortunately these functions are not published by the Umweltbundesamt. Instead, the emission functions are used to compute the emissions for the ten driving patterns, and these figures are published as emission factors. The measurement configuration and the selection of representative cars for the vehicle layers are described in Hassel et. al. (1994).

Since the traffic situations defined by the ten driving patterns are not enough to differentiate in practice between real traffic flows with desirable accuracy, about thirty traffic situations are computed as linear combinations of the driving patterns, and for these situations the emissions factors are given. The computing model proposed by the Umweltbundesamt allows the determination of the emission situation on sufficiently long road stretches. The vehicle fleet can be composed of the defined vehicle layers to reflect the real situation on the stretch in question. The sensitivity with respect to the assessment of traffic control measures is limited by the graduation induced by the discrete definition of the traffic situations. It is one objective of our project to make use of the representative data base provided by the emission factors to develop a procedure for a more sensitive and continuous assessment of traffic control measures.

3. Estimation of Emissions of Simulated Traffic Flows

3.1 Selection of the approach

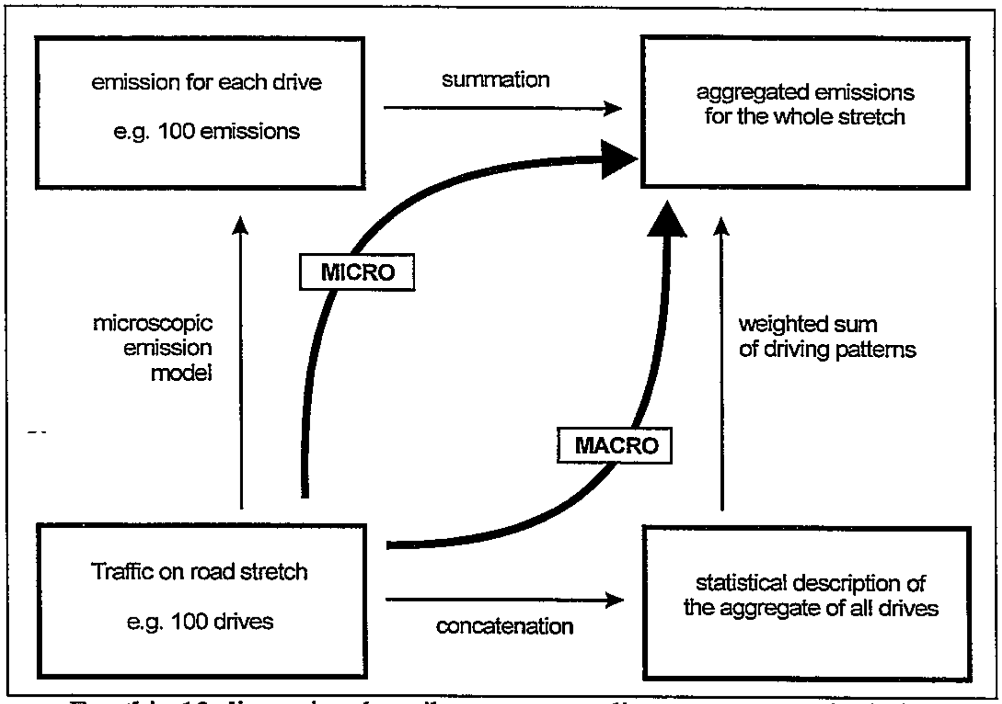
When we started the project, our intention was to compose a given driving profile, simulated or measured in real traffic, out of the standard driving patterns as exactly as possible and by this estimate the emissions produced during the drive as the sum of the combined patterns. But the driving patterns are quite long, i.e. about one hour each, and no information is given about the distribution of the whole emission over the duration of the pattern. Hence, the driving profile to be assessed is not represented by combining patterns sequentially over time, but by a weighted overlay of the best fitting driving patterns. This macroscopic approach is described later in detail.

In addition, a second approach was followed that is based on the existing microscopic emission models. To bring the necessary representativity to those models, an attempt was made to automatically calibrate their input data from the information given in the Manual for Emission Factors, so that for each vehicle layer in the manual a representative car is modelled.

It is possible to go both ways for assessing a traffic control measure; they are in principle shown in figure 1. When the model parameters are calibrated exactly on both the microscopic and the macroscopic side, the two methods should deliver the same results. Under the additional condition, that for the standard traffic situations defined in the Manual the given emissions are correctly estimated by the two procedures, it seems admissible to estimate emissions in other, comparable traffic situations without loosing the representativity.

3.2 Macroscopic approach

In analogy to the definition of traffic situations as linear combinations, i.e. weighted sums, of the ten driving patterns, a macroscopic approach for the computation of the emissions of a simulated driving profile was chosen. The idea is to describe also the driving profile as a weighted sum of the standard driving patterns. In order to determine the weights for the sum, the same thirteen statistical parameters of the driving profile are computed that were used for the cluster analysis to find the ten driving



patterns. For this 13-dimensional attribute vector a distance measure is defined, and on this basis the three driving patterns are selected, that are nearest to the driving profile. To calculate the emission, the emission factors of these three patterns are weighted by the distance to the driving profile and added up.

Figure 1: macroscopic and microscopic approach

This assessment method is able to reflect also slight changes in traffic flow, because it computes an interpolation between the traffic situations defined in the Manual for Emission Factors. The definition of the distance measure is crucial; not all of the thirteen parameters have the same influence on the assessment. It is also critical to assess only a single test drive, especially if it is only a short trip, as it may be convenient for the assessment of a local measure. The driving patterns, on which the emission factors are based on, have a duration of one to two hours, and for shorter drives the computation of the statistical parameters may be less sensible. It is possible to solve this problem by measuring or simulating several test drives through the stretch in question and to compute the statistics over all drives as a whole. In the simulation, the driving profiles of several simulated vehicles of the same type can be combined.

3.3 Microscopic approach

In microscopic traffic flow simulation systems vehicles are modelled with their individual characteristics. The corresponding level of detail for the simulation of emissions would be the exact computation of the state of the engine, based on the instantaneous driving situation and on a detailed model of the vehicle. Such an approach is described in Benz (1984), where for a selection of passenger car types fuel consumption and emission of carbon monoxide and nitrogen oxides are computed with the help of engine maps. This method has the disadvantage, that it is difficult to support the model with the necessary engine maps, because car manufacturers are not willing to provide them.

Another approach for the emission modelling of single vehicle types can be found in Taylor & Young (1996). They do not use engine maps to describe the emission characteristics of a car but a polynomial function of speed, acceleration and a set of vehicle specific parameters. It is possible to calibrate these parameters so that the calculated emissions correspond with the emission factors of a certain vehicle layer, when the model is applied to the basic driving patterns. This is analogous to the selection of a representative car for a layer and measure its emissions on a test bench.

This approach capable to compute emissions also of short test drives, and it can be used to compute emissions in a high spatial and temporal resolution, without loosing representativity for the sum of emissions. The free composition of the vehicle fleet as it is possible with the emission factors of the Manual is also offered by this microscopic approach. It is only necessary, to identify the individually simulated vehicles with the different vehicle types. This is possible, because all cars in the simulation have a set of vehicle specific parameters (e.g. acceleration potential) that allow to distinguish between vehicle types during the simulation of driving behaviour.

3.4 Suitability of simulated driving profiles for calculation of emissions

If emissions are to be computed with the microscopic procedure described above it is important, that the driving dynamics of the simulated vehicles, e.g. the distribution of the acceleration, are modelled exactly, because these values have a great influence on the emissions. In traffic simulation models it is not always possible to model all aspects with the same accuracy, sometimes compromises have to be made on model complexity and accuracy. In the past, the most interesting aspect investigated by traffic flow simulation was capacity. The calibration of the models was therefore tuned in a way to optimise capacity modelling, and often the acceleration behaviour of the single vehicles was modified to achieve this. If such simulation models are be extended to compute emissions, the suitability of the modelling of the driving behaviour must be examined.

In order to check the traffic simulation system we wanted to use, we modelled a real road stretch comprising several signal-controlled junctions and undertook test drives. The comparison of simulated and measured driving profiles showed a good correspondence of the qualitative driving course, i.e. stopping and starting processes at traffic signals etc., and the simulated speeds and accelerations were near to the real values. Differences could be found by inspecting the driving profiles in more detail, it showed that the simulated profile is smoother than the real profile, that means in situations without heavy accelerations the simulated car kept its speed more exactly then the real driver. The influence of this speed noise will be investigated in the further work with the help of our emission measurement car. In general the accuracy of the driving dynamics modelling seems to be sufficient for a microscopic calculation of fuel consumption and pollutant emission at a level of accuracy that is reasonable, when one keeps in mind the quality of the emission base data.

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