Integration von dynamischer Verkehrs-simulation und Wirkungsanalyse für die Entwicklung ressourcenschonender Verkehrsmanagement-Strategien

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Abstract / Kurzfassung: Um zu verhindern, dass die Nutzung von Telematik zu unerwünschten negativen Effekten führt, müssen Verkehrsmanagement-Strategien jenseits der üblichen nutzeroptimalen Lösungen entwickelt werden. Mit diesem Ziel werden in dieser Arbeit dynamische Verkehrssimulationsmodelle und verfeinerte Prognose- und Auswertungsmodelle gekoppelt, mit denen Strategien hinsichtlich ihrer Umweltwirkungen und wirtschaftlichen Effizienz bewertet werden können. Hierfür stehen dynamische, mikroskopische Verkehrsmodelle zur Verfügung, die im Rahmen des „stadtinfoköln"-Projektes zu Prognoseinstrumenten weiter entwickelt werden. Als Ergebnis der Integration dieser Modelle mit Modellen zur strategischen Prognose und Bewertung von Verkehrswirkungen lassen sich erste Bandbreiten für die Wirksamkeit und Effizienz einzelner Verkehrsmanagement-Maßnahmen abschätzen. Gleichzeitig wird die Notwendigkeit zur Verfeinerung der Umweltmodelle deutlich, um den dynamischen Aspekten des Verkehrsablaufes Rechnung zu tragen. Daher werden Modelle zur Emissionsprognose im Straßenverkehr weiterentwickelt und mit vorhandenen Simulationsmodellen (PELOPS) abgestimmt, welche die Fahrdynamik der Fahrzeuge berücksichtigen. Auf Basis der Ergebnisse werden erste Szenarien für Management-Strategien gezielt so entwickelt, dass vorgegebene Umwelt- und Sicherheitsziele erreicht und Wirtschaftlichkeitskriterien maximiert werden. Mittelfristig ist das Ziel, intelligente Entscheidungsunterstützungssysteme aufzubauen, die Verkehrsmanagern bei aus gemessenen Verkehrsdaten rekonstruierten realen Verkehrssituationen effiziente, ressourcensparende Lösungen von Verkehrsproblemen offerieren.

Schlagworte: Verkehrsmanagement, Telematik, Mikroskopische Verkehrssimulation, Emissionsmodelle, Strategische Bewertung

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1 Introduction

A challenging task of today's transport management and planning is to develop solutions for an efficient and environmentally friendly transport system. Especially in congested urban areas, where infrastructure extensions are limited by financial and space restrictions, innovative traffic management strategies are necessary in order to achieve a spatial and temporal redistribution of traffic. In this context, a great hope lies in the application of intelligent transport systems (ITS) which, on the one hand, provide users with information on the current state of the transport system, and, on the other hand, offer technical solutions for dynamic traffic management with a focus on achieving strategic objectives.

However, traffic system authorities face the situation of potentially conflicting goals that have to be weighted against each other such as
- improving the movement of people and goods as well as reducing urban traffic congestion,
- achieving environmental objectives (air quality, safety, noise etc.) as well as
- social and economic goals (accessibility, economic viability, equitable transport system).

Therefore, the focus of our work is to develop transport management strategies beyond user optimal solutions which avoid congestion and take into account environmental restrictions. For this purpose we need tools that enable us to analyse how to obtain an optimal system state under environmental and equity objectives and balance these against individual priorities. We therefore integrate dynamic microscopic traffic simulation models with environmental and economic assessment tools. Advanced traffic simulation tools are available that are currently improved in the stadtinfoköln-project towards forecasting capabilities. Due to the computational efficiency of the simulator, it is possible to calculate environmental impacts on the basis of individual vehicle units in reasonable time, even for huge networks (about 10^6 cars). Simultaneously, it is necessary to demonstrate the capability of the model to reflect the effects of transport measures on traffic conditions and environmental impacts accurately. For this purpose, we compare the results of the integrated model with an existing, highly differentiated microscopic simulation model (PELOPS).

Finally, by the application of the integrated traffic and environmental impact simulation model, we can use the data from the stadtinfoköln-project to identify environmental hot spots in the network of the city of Cologne and derive first bandwidths for potential effects of transport management measures.

The intention of this co-operation is to develop intelligent decision support systems that supply information on efficient and environmentally favourable traffic management strategies based on the actual traffic situation. Within the next decade, ITS will offer the technical solutions to actually apply these strategies by providing precise information on the current state of traffic (e.g by using Floating Car Data) and by providing means for flexible traffic management such as centralised route guidance systems (RGS) (in-vehicle, dynamic traffic guidance) or electronic tolling systems.

2 Traffic Flow Models

2.1 Simulation of Large Networks

In order to analyse the effects of traffic management strategies on street network conditions and subsequent environmental impacts, it is necessary to apply dynamic traffic simulation tools that model a large number of individual driver-vehicle units and their mutual interactions in reasonable time. Such models are already in use today, but – although computational power has grown rapidly over the last decades – one usually has to balance out between the spatial area to cover by the model and the accuracy required. In our project, we apply a dynamic microscopic transport model which is targeted for the simulation of large networks, in this case for the study area of Cologne.

For the simulation of, for example, the roughly two million trips happening in Cologne each day, fast algorithmic approaches are needed, therefore the interaction of cars with each other and with traffic management systems are represented by a simplistic approach [1], [2]. One of the main features of the approach is its computational efficiency while it allows the computation of traffic flows still being microscopic (i.e. each driver-vehicle unit is treated individually with its own specified route) and dynamic. This is achieved by using a representation, where each link of the road-net is modelled as a waiting queue: cars that enter the queue (the link) have to stay there for at least the minimum travel time. After this time, they can reach the next link in their route-plan only if there is enough space there, and if the capacity of the link they are occupying allows this (capacity means the maximum flow out of the link). Since the cars are being touched by the simulation program only a few times during their stay on the link, this method is capable of simulating Cologne in some 30 minutes CPU-time. However, in order to use a valid description of the traffic flow pattern in the city, the model has to be run a number of times in order to get an approximation to the dynamic user equilibrium. This has been done by emulating the try-and-error-process, that assumed users utilise in order to find their best route through an unknown road-net [1].

Since the model can simulate a few million cars in real-time, it is capable of predicting the traffic some time in the future by simply computing faster than reality, provided the input data (origin-destination matrices (ODM) or the trip tables) are correct. The model is currently being used in a large German project named “stadtinfokoeln” for a similar purpose [3]. There, a standard demand computation has been used, however in order to have a time-dependent ODM the demand has been computed for every hour of the day [4]. This demand computation needs as input the socio-demographic population data and some infrastructure data such as the locations of the working–places, or in general, the occasions for a variety of different activities. Additionally, the road-net and the public transport schedule and –net have been used in order to separate the individual traffic from the remaining transportation means.

First results, depicted in figure 1, show that the driving dynamics of the model generates sufficiently realistic driving patterns that can be used for the computation of emissions and other impacts of traffic on an aggregate scale.

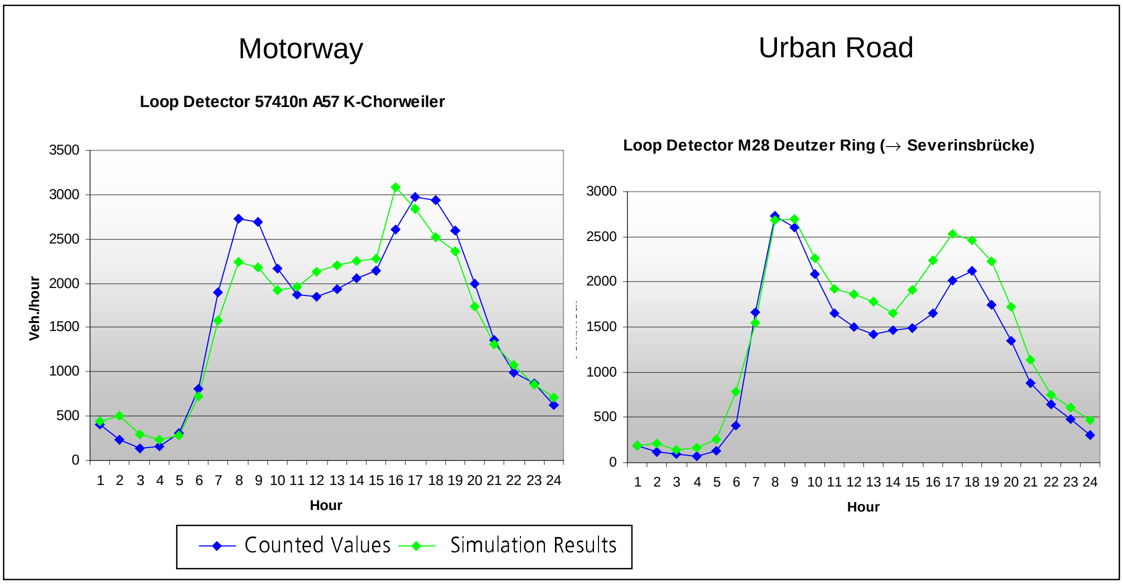

Figure 1: Comparison of Simulation Results with Real World Data

However, if statements on the effectiveness of traffic management strategies are to be made, it is necessary to demonstrate that the microscopic model is capable of simulating the major effects of different dynamic situations. Therefore, a comparison has been performed of the results of the microscopic model PLANSIM-T [5] with the highly detailed traffic flow model PELOPS [6], which allows to take all interchanges into consideration that occur between driver, vehicle and traffic and which is used for the evaluation of traffic- and infrastructure-supported traffic influence measures and driver assistant systems.

2.2 Comparison of Two Stochastic Traffic Flow Models

For our comparison, different dynamic situations for a single stretch with a fixed geometry have been simulated using PELOPS as well as PLANSIM-T. PELOPS represents a combination of vehicle- and traffic-specific models, its advantage being the possibility to take all interchanges into considerations that occur between driver, vehicle and traffic ([6] - [8]). The centre of the program is formed by the three crucial elements of traffic systems - stretch/environment, driver and vehicle. With these elements PELOPS is able to simulate traffic in extremely high accuracy, enabling a realistic depiction of complex driving manoeuvres such as Stop&Go traffic. This is a major requirement for the investigation of fuel consumption and emissions, and also for the design and analysis of driving assistance systems.

The approach used in PLANSIM-T ([2], [5]) is much more simple and based on a minimal set of update rules. The underlying model is a microscopic car-following model in which drivers adjust their velocity in each time step according to the vehicle in front in such a way that safe driving is assured. Investigations of the model show that despite its simplicity it is able to reproduce the properties of congestion very well and velocity changes are performed in a realistic way. Another major feature is its computational efficiency: compared to PELOPS it is computationally around 1000 times faster.

In all driving situations that have been simulated, the same geometry has been used. A highway was simulated that contains a bottleneck at its end. Starting with three lanes there is a reduction of lanes after 5.5 *km*. In this case the most right lane ends. Along the highway loops were placed that collect the dynamic information of the cars. Results are shown as samples over 1 *min*. On the highway, there is a speed limit of 100 *km/h* but there is portion of drivers that simply ignores that restriction. Moreover, the fleet of vehicles consists not only of one prototype but there is a mix of passenger cars and lorries. While in PELOPS the ignorance of the speed-limit is a result of the selected individual that drives the car, in PLANSIM-T the distribution of vehicles has to be adjusted in an adequate way.

Before taking a closer look on the results it has to be stated how the results can be interpreted. Both models are intrinsically stochastic. Since for each situation only one run has been performed, results are quite dependent on the random seed that was chosen. Due to its high computational expense, a sampling over a big amount of simulations could not yet be accomplished with the PELOPS model. Therefore, the reader is asked to focus on the major trends below, but should not expect to get complete agreement between the results of the two models. The results one gets are anyway quite non-sensitive on the random seed chosen for PLANSIM-T.

2.2.1 Free Flow Situation

For the first scenario the system was fed with a continuous increase in traffic density starting from 10 veh./km to 25 veh./km. The systems behaviour clearly shows a free flow situation. The parameters of the PLANSIM-T model (desired velocities, vehicle length, maximal acceleration/deceleration, choice of right lane) have been applied according to the given data .

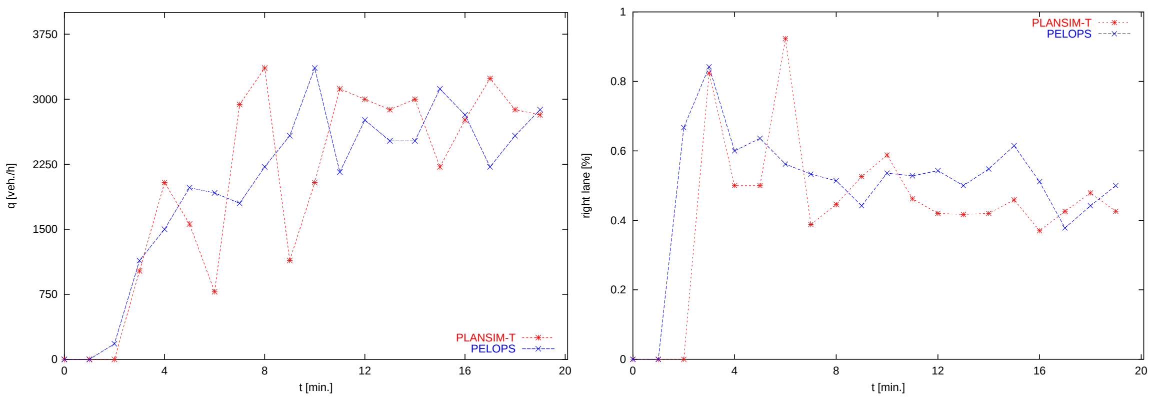

Figure 2: Comparison of flow and usage of right lane at bottleneck in free flow situation

In the comparison of the flow in both systems and the usage of the right lane, PLANSIM-T produces more fluctuations than PELOPS which might be due to a less scrupulous driving behaviour. Moreover, PLANSIM-T does not contain a real decision model for the threading of a bottleneck. Figure 2 shows the results for the location at the bottleneck.

2.2.2 Congested Flow Situation

The system was fed with a continuous increase in traffic density starting from 20 veh./km to 35 veh./km. The PLANSIM-T parameters are the same as in the free flow case. The systems behaviour for the congested flow clearly shows a breakdown of traffic inside the bottleneck (see figure 3).

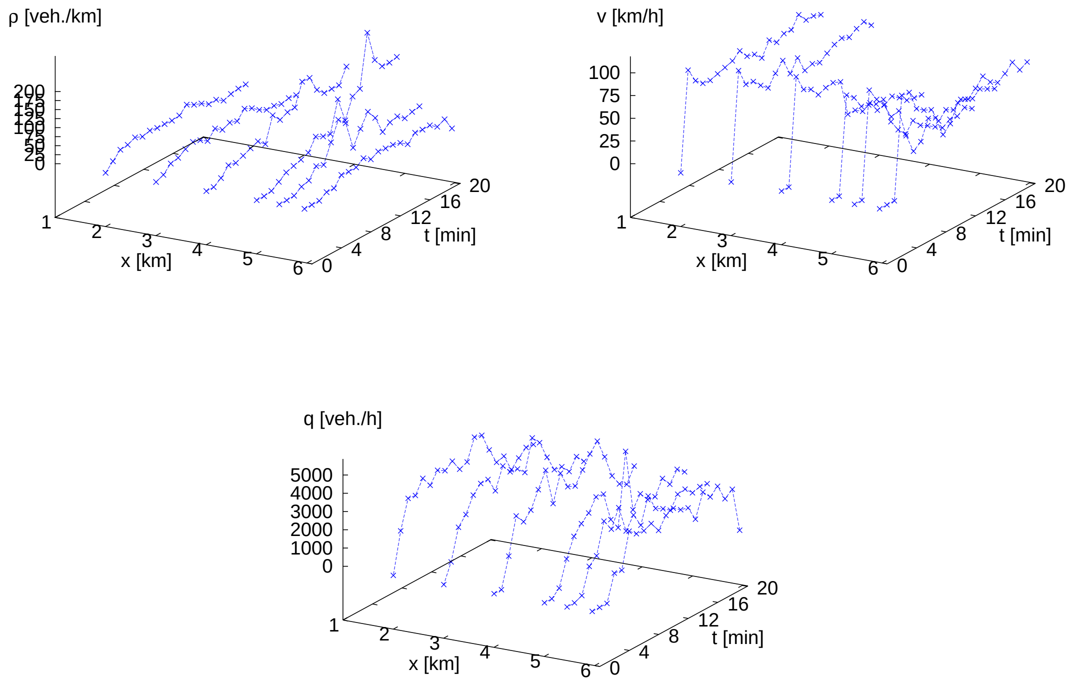

Figure 3: Temporal development of the dynamic quantities density, velocity and flow at different detection sites. The bottleneck is located around 5.5 *km*. The density increases slightly over the time from *20 veh./km*. One can clearly see the decrease of the velocity due to the breakdown of traffic inside the bottleneck

The comparison of the results for the flow and the usage of the right lane for three locations (In, Bottleneck, End) shows that both quantities are well reproduced by the PLANSIM-T model (see figure 4).

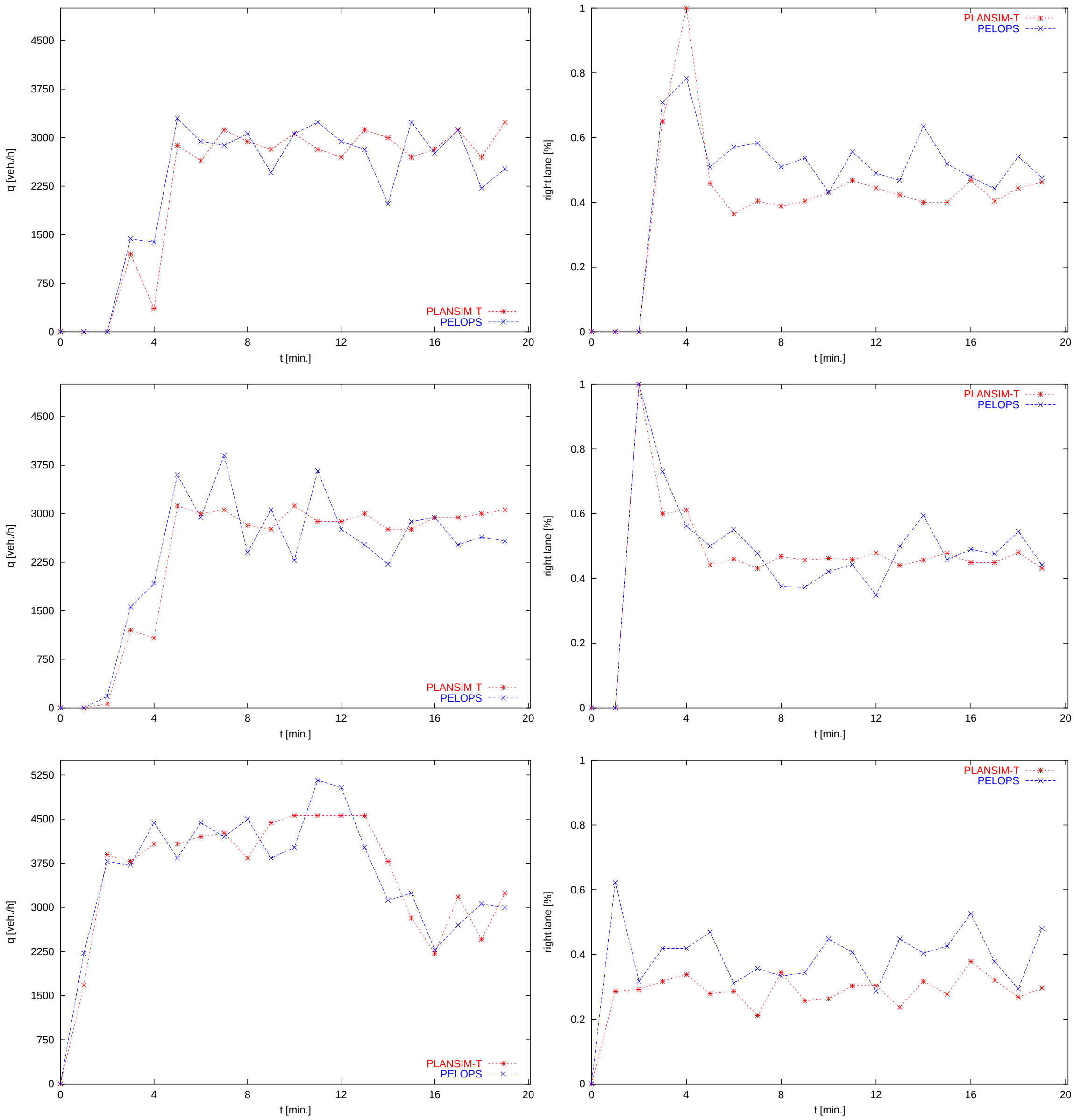

Figure 4: Comparison of flow and usage of right lane in congested flow situation

3 Integration of Impact Assessment Models

Thus, overall the traffic simulation provides detailed and accurate data on the dynamic properties of traffic flow on all links of a given transport network. These data can now be used in the assessment of emissions of environmental and economic impacts. In our project we integrated models for gaseous substances, energy consumption, noise emissions, noise exposure, and economic impacts. For the start, existing models from transport planning have been used.

3.1 Models for Emissions of Gaseous Substances and Energy Consumption

The emissions of gaseous substances for a single vehicle depend on a large number of parameters: the vehicle/engine characteristics, the operational point of the vehicle, the driving situation and the environmental conditions at a given moment. The baseline data for the determination of road vehicle emissions is generally gained by measuring the emission behaviour of representative vehicles in a laboratory setting by simulating specific driving conditions. For modelling purposes in the context of transport planning, these sets of measurements are usually aggregated either by estimating a functional relationship (e.g. the German recommendations for economic assessment of road infrastructure investments EWS, [10]) or by clustering the data into typical driving situations (e.g. the Workbook on Emission Factors for Germany and Switzerland, [11]).

In our project the dynamic reactions of travellers to management measures are of interest. The microscopic traffic models provide data on the speed, acceleration and deceleration of vehicles, however not on the vehicles operational point. It is therefore necessary to apply an approach that is capable of reflecting changes in emissions due to changes in these driving parameters. This prerequisite is fulfilled by the functional relationship approach, e.g. applied by the EWS. The basic function for the calculation of the emission factor *ef* for vehicle type *vt* and pollutant *i* depending on velocity *v* is given by

$$ef_{i,vt}(v) = \begin{cases} (c_0 + c_1 \cdot v^2 + \frac{c_2}{v}) & for\ \ v > 20km/h \\ \min\left\{c_s, (c_0 + c_1 \cdot v^2 + \frac{c_2}{v})\right\} & for\ \ v \le 20km/h \end{cases} \qquad [g/(km \cdot Veh.)] \qquad (1)$$

with parameters c_0, c_1 and c_2 for free flow and parameter c_s for stop-and-go traffic differentiated by vehicle type and pollutant.[1] A reduction factor is applied for each pollutant in order to take account of advanced pollution reduction technologies.

Figure 5 shows first results of the emission calculation. Emissions have been calculated for all links of the road transport in an hourly resolution. In order to derive comparable emission indicators for the town area, these emissions have been assigned to elements of a standardised grid (EMEP grid [12], here 1 x 1 km^2).

The results shown here allow first conclusions on the spatial and temporal distribution of emissions. However, further investigation is necessary into how capable the approaches using aggregate emissions factors are of simulating traffic influencing measures [9]. Preliminary comparisons of these approaches with the results of the much more detailed PELOPS model indicate that there is a need for the development of more adequate microscopic emission factors.

[1] These emission factors are adjusted to the road gradient by a correction factor, which is not relevant in our case study.

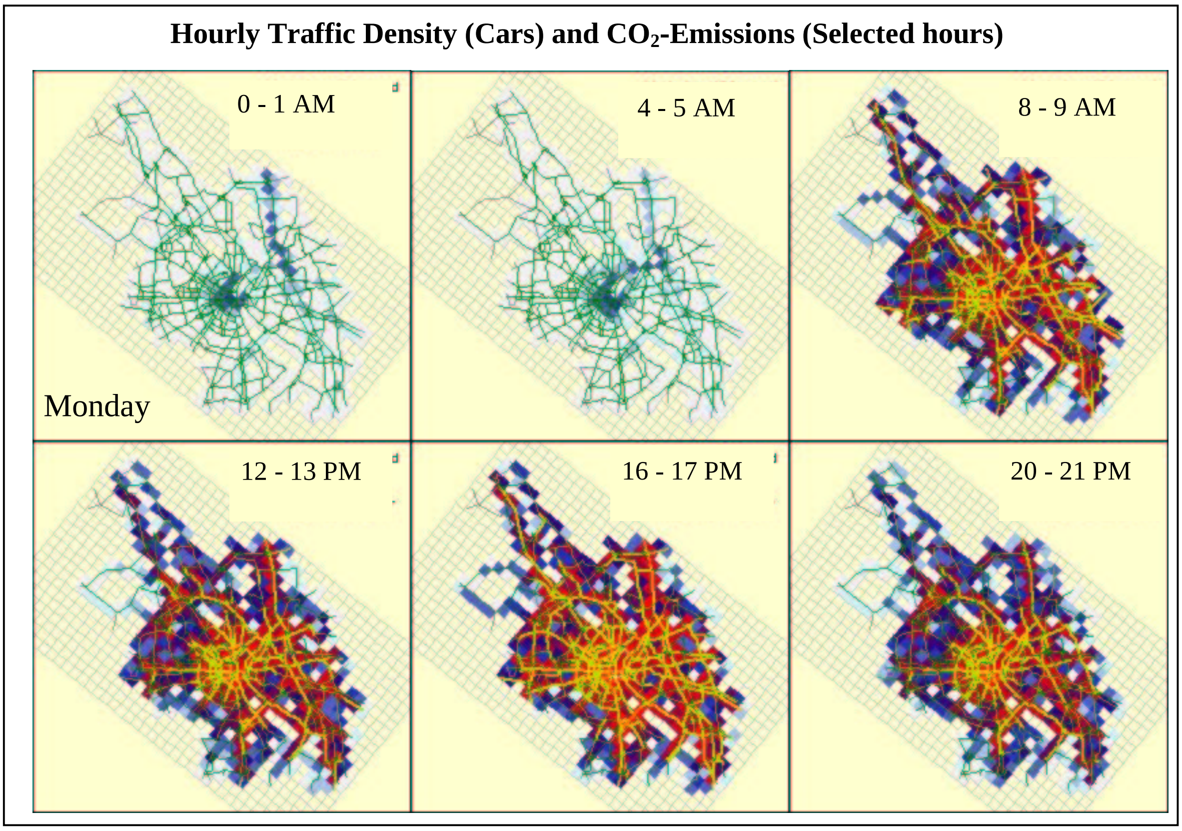

Figure 5: Hourly Traffic Density and CO_2-Emissions

3.2 Modelling Noise Emissions and Exposure

Similar problems arise when modelling noise emissions. Transport noise models are applied in the context of the implementation of noise abatement regulation. These models calculate noise levels or noise exposure at specific points in the vicinity of transport infrastructure. In this project, the reference noise level of road transport is calculated based on the noise protection manual for roads in Germany (RLS-90) [14]. Input parameters for the calculation of emissions (equivalent sound pressure) are traffic flow, vehicle mix, speed limit, road coating, and gradient, the noise spread is determined by distance, height, topography, and meteorology. This model has been enhanced by the inclusion of reflections via the application of typical housing structures depending on the type of road. The latter are also applied to predict the number of inhabitants that are exposed to noise levels above a specified target. These are again assigned to the elements of the standardised grid.

3.3 Modelling the Economic Impacts of Strategies

Cost-benefit and multi-criteria analysis are common tools in the assessment of transport infrastructure throughout Europe. Therefore, cost values for economic impacts are available from standardised approaches for infrastructure planning. In our project, we apply an approach based on the economic assessment of projects in German transport infrastructure master planning. The variable cost parts that are considered besides infrastructure and maintenance costs are vehicle operating and maintenance costs, revenues, generalised costs (time loss e.g. due to congestion) and accident costs (personal loss, health costs, and material damage).

3 Development of Transport Management Strategies

Commonly, the assessment of infrastructure projects as well as transport strategies follows the procedure of first defining a strategy or planning measure, then forecasting its effects and finally evaluating these by means of multi-criteria analysis (MCA) or cost-benefit analysis (CBA). This means that either environmental impacts have to be explicitely weighted against other impacts (MCA) or be valued in monetary terms (CBA). Both methods have major drawbacks, especially in the consideration of environmental risks, of irreversible damages, and of the interests of future generations [15]. The result of the procedure is a statement whether a certain strategy is preferable or not. However, in our project, the strategies have to be the outcome of an optimisation process. For these reasons, the *backcasting approach* is commendable which has recently been applied in a number of projects ([13], [16], [17]). This approach is based on the definition of environmental objectives and indicators which can be used as restrictions in the optimisation process. In an iterative process, different strategies are evaluated with respect to the achievement of these targets until at least one valid solution is found. From a set of feasible strategies that strategy is finally chosen that maximises the economic welfare of society. Thus, it is possible to develop cost efficient measures that fulfil the requirements of environmental sustainability.

A major requirement is the definition of environmental targets that reflect safe minimum standards according to the rule that "destruction of irreversible natural stock should be avoided unless the social costs of conservation are unacceptably large" [18]. Based on a literature survey [15] the following standards are proposed for our project as a first working base:

- reduction of CO_2-emissions and fuel consumption by 30% compared to status quo,
- target levels for noise exposure: 55 dB(A) night-time, 65 dB(A) day-time,
- reduction of fatalities and severe injuries by 40% each,
- reduction of NO_X and VOC emissions by 30% each,
- reduction of emissions of particles and benzene by 90% each.

These targets will in a second step be regionally differentiated according to data on the sensitivity of the environment.

3.1 Strategies for the Reduction of Noise Exposure

The noise situation described above has shown that it is necessary to develop reduction strategies which take into account the time and place of occurrence. Parameters that influence the development of noise are traffic flow, traffic mix (share of trucks), speed, and coating; noise exposure is further influenced by the population density in affected areas and environmental variables such as meteorology and topography. In a first test, we keep all parameters but the traffic speed constant in order to evaluate what effect can be achieved by a targeted reduction of speed limits in highly affected areas and during high-exposure time. Therefore, for streets where the noise target level has been exceeded at night-time, the speed limit has been decreased by 10 km/h at night, respectively if the day-time target was exceeded, the speed limit was equally decreased during the day. Figure 6 shows the effects of this measure on noise exposure and user costs over the day. However, the effect does not yet include a modified route choice of users due to the change in travelling times.

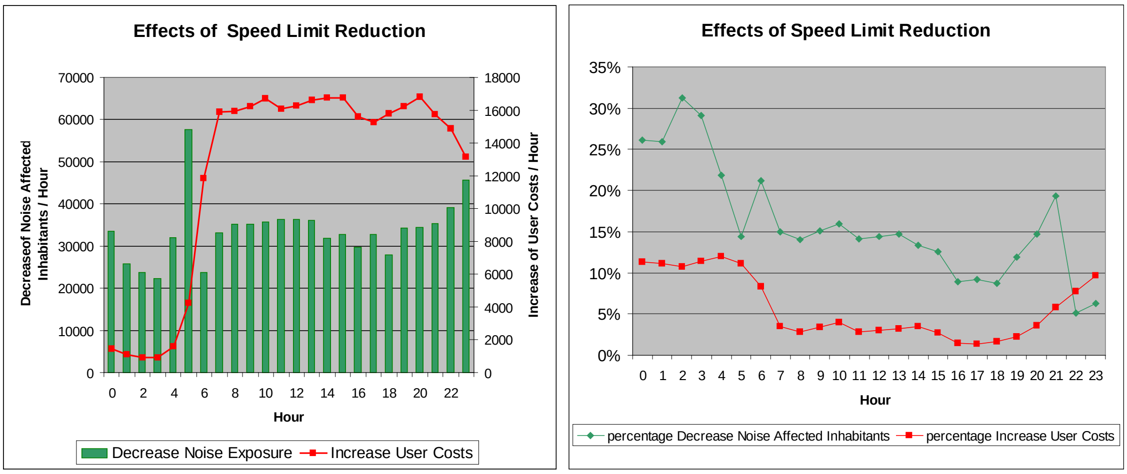

Figure 6: Effects of Speed Limit Reduction on Noise Exposure and User Costs

The highest reductions could actually be achieved during the morning peak hour. In total, the noise exposure of inhabitants, measured by the total amount of hours where inhabitants are affected by noise above the target level, could be decreased by 13% while the user costs where increased by 3%. This equals costs of about 0.15 € per inhabitant and hour exposed. The problem of this approach is that user costs are counted and weighted with every second of time loss, therefore the cost values are extremely high. As a comparison, the EWS suggests a basic cost value of about 40 € per year and inhabitant which increases with the value of the target level exceedance. Figure 7 shows that the main improvements could be achieved in the city centre.

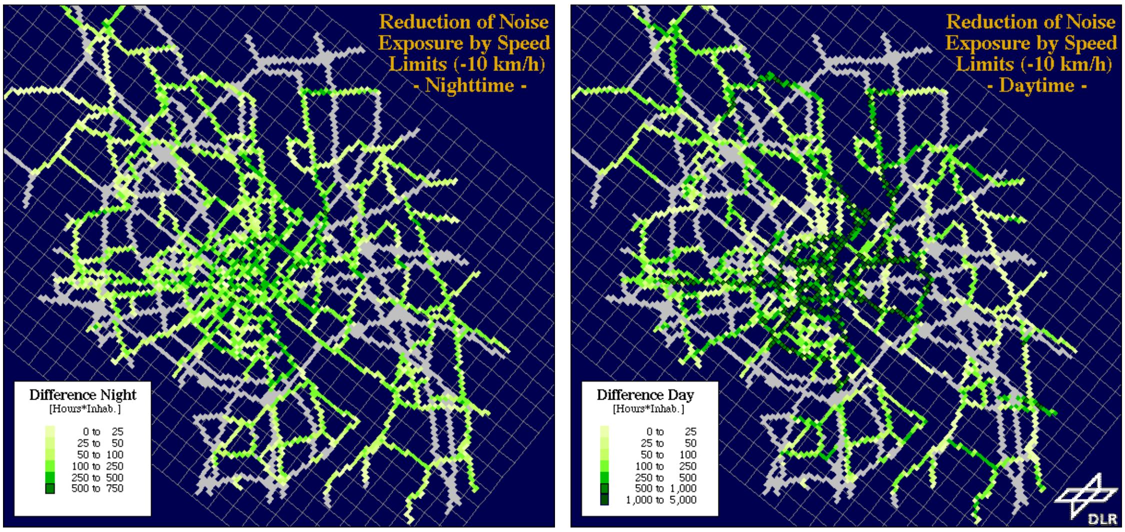

Figure 7: Local Improvements of Noise Exposure due to Speed Limit Reduction

Though a significant reduction of noise exposure could be achieved, the target levels of 55 dB(A) at night-time and 65 dB(A) at daytime are by far not achieved. Therefore, it is necessary to further strengthen the efforts for noise reduction. However, the effectiveness of this type of measure –reducing speed– is limited: According to the RLS-guidelines on noise protection, a maximum of about 9 dB(A) reduction can be achieved by reducing speed limits from 100 km/h to 20 km/h. Another drawback is that below 20 km/h (i.e. in congested traffic situations) a valid statement is not possible on the basis of the noise models that are available for the assessment of transport infrastructure projects. Other measures that will be tested in the next steps are a differentiated re-routing of travellers and technological measures that reduce noise emissions of vehicles. In future it could be possible to provide access to restricted areas at certain times based on information on vehicle’s noise characteristics that is provided by intelligent transport systems. However, for the purpose of assessing such traffic management strategies it will be necessary to develop more refined noise emission and exposure models.

3.2 Strategies for the Reduction of Emissions and Fuel Consumption

Besides traffic flow, congestion does have a strong influence on the quantity of emissions that is produced. A third important factor is the technology that is applied to reduce emissions and fuel consumption. Hence, strategies can be thought of that improve the traffic flow in order to reduce congestion, reduce the total amount of road traffic and/or encourage the introduction of environmentally friendly technologies. In a first step, we estimate the emission reduction potential of strategies for traffic flow improvement. Figure 8 displays the average specific emission during the day for CO_2.

It shows that during congested situations the average specific emissions are about 75% higher than under free flow conditions. Let us assume that it would be possible in peak hours to manage the same traffic flow without congestion, i.e. the minimum average specific CO_2-emissions could be applied to these flows as well. Then a total reduction of CO_2-emissions of about 30% could be achieved. Since of course our first assumption does not hold true, this value only indicates the absolute maximum of emission reduction that would be possible by introducing intelligent traffic management systems.

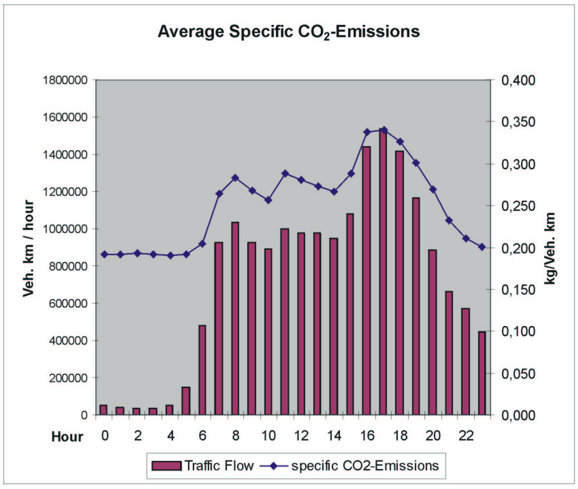

Figure 8: Average specific CO_2-emissions

Since CO_2-emissions are strictly proportional to fuel consumption, these conclusions hold true for fuel consumption as well. A different situation can be observed for NO_x-emissions. Since NO_x-emissions show a strong speed dependency, a reduction of congestion that comes along with an increase in speed does not lead to a decrease as for CO_2-emissions. On the other hand, a reduction of speed has the contrary effect: the speed limit reduction that has been assumed in the noise case leads to decrease of NO_x-emissions by 1.5% but to an increase of CO_2-emissions by 1.5%. Therefore, other measures that are directed towards achieving a steady traffic flow at an optimal speed have to be developed. Until now, the influence of traffic signals and other measures that influence driving patterns cannot not been considered in the emission models. For example, technologies could be implemented that improve the anticipation of traffic situations by drivers. This shows the importance of developing adequate emission models which are capable of reflecting dynamic changes at a network level.

Additionally, technical measures that are available to reduce emissions will be analysed. As in the case of noise, it can be imagined that specific, sensitive city areas will be priced or restricted for access depending on the emission reduction equipment or type of vehicle. For example, the use of zero emission or alternative propulsion vehicles could be encouraged by this kind of measures. The emission and fuel consumption reduction potential of technological measures is expected to be very high. For example, EWS state a reduction of fuel consumption by cars between 1990 and 2010 by about 15%, of NO_x-emissions by about 90% for gasoline, 50% for diesel cars. The technological potential for reducing fuel consumption of cars is presently analysed in an ongoing project of the DLR. However, assuming a further increase in traffic demand, this technological potential might be consumed soon. Therefore, additional transport management measures that aim at a modal shift towards less energy consuming transport modes will be analysed. This requires the development of multi-modal dynamic transport and assessment models, an integration of intelligent traffic systems and cross-modal management strategies.

4 Conclusions / Outlook

With our work to date we have laid the foundations for developing innovative strategies for a transport management beyond user optimal solutions. Fast microscopic and dynamic transport models for road traffic are available that simulate the reactions of users to interventions into the transport system with high accuracy and thus can be used in traffic management systems as well as serve as a basis for the assessment of management strategies. For a comprehensive transport management in urban areas it is necessary to extend these models to other transport modes such as public and non-motorised transport.

Environmental and economic impact models have been applied that have initially been developed for transport planning purposes. Though these models provide satisfactory results for a first assessment of strategies it could be seen that there is still substantial research demand for developing models that are capable of mapping impacts at a dynamic and microscopic scale which is necessary in order to assess the impacts of management strategies. Nevertheless, through the application of these models some experience has been gained on potential transport management strategies in the examined study area that could be applied in order to avoid or minimise negative environmental impacts.

A major requirement for our future work is the formalisation of the problem of finding the system optimum under environmental constraints and economic efficiency in order to automatically generate optimal strategies. The implementation requires operational criteria for the assessment of strategies; the formulation of a general cost function in a multi-criteria decision context in order to define what the system optimum is meant to be; detailed information on the reaction of transport users to measures; and the development of fast tools for the simulation of traffic and environmental impacts as well as for the assessment of strategies in order to find system optimal solutions depending on the current state of the transport system.

From the results of our research project it will then be possible to assess whether the application of intelligent transport management systems will be feasible in future traffic guidance centres and will support traffic supervisors in their decision on best traffic management strategies.

Acknowledgements

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