BENEFITS OF USING MICROSCOPIC MODELS FOR SIMULATING AIR QUALITY MANAGEMENT MEASURES

Daniel Krajzewicz, Corresponding Author
Institute of Transport Research, German Aerospace Center (DLR)
Rutherfordstr. 2, 12489 Berlin, Germany
Tel: +49/30/6705-5273; Fax: +49/30/67055-283; Email: daniel.krajzewicz@dlr.de

Rita Cyganski
Institute of Transport Research, German Aerospace Center (DLR)
Rutherfordstr. 2, 12489 Berlin, Germany
Tel: +49/30/67055-147; Fax: +49/30/67055-283; Email: rita.cyganski@dlr.de

Matthias Heinrichs
Institute of Transport Research, German Aerospace Center (DLR)
Rutherfordstr. 2, 12489 Berlin, Germany
Tel: +49/30/67055-174; Fax: +49/30/67055-283; Email: matthias.heinrichs@dlr.de

Jakob Erdmann
Institute of Transportation Systems, German Aerospace Center (DLR)
Rutherfordstr. 2, 12489 Berlin, Germany
Tel: +49/30/67055-232; Fax: +49/30/67055-289; Email: jakob.erdmann@dlr.de

Word count: 5,802 words text + 6 tables/figures x 250 words (each) = 7,302

Submission Date: 1st of August 2015

ABSTRACT

The raising of awareness about air pollution has brought about legislative regulations that force local administrations to keep the concentrations of certain pollutants under the formulated thresholds. A large variety of measures have been implemented to reduce road traffic's emissions on the local level, but the observed results are not always satisfactory. For determining the effects of such measures a priori, a simulation system could be used. Because of the high variability of traffic management measures, such a system must be capable of replicating changes in traffic flow, the vehicle fleet, as well as user behavior, including modal shifts, as well as the interactions between these parts. Often, the effects of a measure can be found in a bigger region than the directly influenced one. Thus, the system must be able to simulate traffic in large, city-wide areas. This report emphasizes why the usage of microscopic models for this purpose makes sense nowadays. It introduces an exemplary system and presents some initial results.

Keywords: air quality, vehicular emissions, microscopic simulation, agent-based modeling

INTRODUCTION

Reduction of emissions produced by road traffic is a target addressed worldwide (*1*, *2*) and is pursued by different actors. Regulations for upper pollutant limits can therefore be found in many nations (*3*). While this report discusses examples from Europe, and in particular Germany, the assumptions and methods are applicable to other parts of the world as well and are thus internationally relevant (*4*).

In the European Union, the legislatures have formulated a set of regulations that force different stakeholders to undertake measures for reducing the amounts of emitted pollutants and for increasing and/or maintaining air quality. For instance, the European Parliament and Council formulated the “Directive 2008/50/EC on ambient air quality and cleaner air for Europe” (*5*), which poses limits for the concentrations of a set of pollutants and was implemented in national law by several EU member countries. Some of the pollutants under consideration are closely related to vehicular traffic, the main ones for our purposes are PM (particular matter) and NO_2 (nitrogen dioxide). Regarding the (*5*) directive, local authorities are the responsible bodies for keeping the air quality in the prescribed limits. A large number of different measures for lowering emissions generated by road traffic have been performed in the past years. They range from building or restricting the road infrastructure, to renewing distinct vehicle fleets, right down to fostering public transport and soft transport modes. But, as discussed at a later place in this report, a closer look reveals that only some of them have been successful.

The research presented herein is targeted at the design of a software tool that predicts the effects of large-scale traffic management measures on the amount of emitted pollutants using simulations. The final goal is to determine the most appropriate solution given an arbitrary city. A purely microscopic simulation is attempted here, including demand generation, traffic flow model, and emissions computation. The motivation for using a microscopic approach will be given in the following sections.

The development presented here is in line with the trend towards increasingly fine-grained, microscopic models. Earlier examples for evaluating traffic management measures for air quality improvement include the application of the SATURN traffic assignment model in conjunction with an emission and a dispersion model to determine the effects of introducing traffic calming via pedestrianization (*6*). In (*7*), a support tool for traffic planners is presented, which uses macroscopic measurements for city-wide emissions computation. Some recent work has been performed using the mesoscopic MATSIM traffic simulation. In (*8*), MATSIM is used in conjunction with the inventory emission model HBEFA (*9*) for simulating city-wide air pollution tolls. In (*8*), not only a mesoscopic simulation is used instead of a macroscopic one, the size of the simulated area is also increased from a city center to a city-wide network. In addition, the MATSIM approach uses a microscopic agent-based demand generation model instead of relying on a macroscopic demand. A similar though noteworthy approach is (*10*), which sets individual behavior against pollution generation and exposure. After being extended by built-in emission models, the microscopic traffic simulation SUMO (*11*, *12*) was used for determining large-scale effects of traffic management measures as well, e.g. (*13*). The report at hand presents an extension to (13) by incorporating the microscopic agent-based demand model TAPAS.

The remainder is structured as follows. At first, the measures considered are described. Microscopic tools and models for simulating traffic flows, for computing the demand, and the emissions produced by traffic are discussed afterwards. This is followed by a presentation of the combined system that is capable of determining the effects of traffic management measures taking into account the user responses beyond changes in their route choice. Then, two example applications and their results are given. This report ends with a summary.

TRAFFIC MANAGEMENT MEASURES FOR AIR QUALITY

The research presented here focusses on traffic management measures that are applied to the traffic system of a city. In the following, we disregard vehicle-based approaches, such as designing more efficient engines or downsizing them. Such changes in the vehicle fleet are implicitly modeled when assuming valid models for car ownership or the vehicle fleet. In-vehicle ITS solutions that aim at or are supposed to reduce emissions, such as speed advisories (*14, 15*) or navigation systems (*16*), are also ignored herein. The major reason for not regarding them is that their introduction is performed by individual drivers instead of being dictated by authorities. Of course, these systems' performance has to be evaluated as well, but within the research presented here, they have to be modeled within the traffic simulation as an intrinsic feature of a part of the simulated vehicle fleet.

A very fruitful source of information about traffic management measures that target the improvement of air quality is MARLIS (*17*), a database developed by AVISO GmbH for Germany's road administration BASt. MARLIS' version 3.0 contains the descriptions of about 3,500 traffic management measures that have been or are planned to be performed. While the majority of these measures are located in Germany, examples from other countries are included as well. For every measure, besides other information, the targeted pollutant to reduce (PM_{10} and NO_x are addressed by MARLIS), the status of implementation (planned/performed), the quantified effect after implementation (if available) and the city the measure was realized within are given. The measures are additionally classified into one of the following categories: infrastructure and building measures, traffic regulation and management, public transport, pedestrian and bicycle traffic, traffic calming, traffic smoothing, parking, commercial transport, public relations, and other measures. Some of these categories are further sub-divided. One should note that although every "measure" is assigned explicitly to a single category, some actually describe a package of measures of different types.

When looking at the effects, one may note that most are below the expectations. (*18*) states that about 45% of the measures have a low impact on air pollution and the remaining only a moderate one. Therefore, the implementation of a system that supports in choosing an appropriate measure a priori should be assumed to achieve both: reduce costs by avoiding the implementation of ineffective measures, and improve the air quality by choosing a measure that matches the regarded city's needs.

MICROSCOPIC MODELING OF CITY-WIDE EMISSIONS

The following sub-sections give a motivation for using microscopic tools, including the traffic flow model, the demand generation model, and the emissions model, respectively. Besides naming the advantages, they as well describe the issues found when using microscopic tools and propose solutions.

Microscopic Traffic Flow Simulations

Microscopic traffic simulation models have been known since the 1950s (*19*) and are a tool accepted by both academia and commercial users. In contrary to macroscopic simulations (*20*) that model the progress of the aggregated measure "traffic flow" through a given road network, microscopic traffic flow simulations simulate each driver-vehicle entity explicitly. The longitudinal movement through the road network is usually reproduced using so-called car-following models, while the lateral behavior uses a second model for choosing the lane (*21*). Modern microscopic traffic simulations support different modes of transport, including pedestrians, bicycles, public transport, etc. The following statements are mainly built upon experiences gained while working with the microscopic traffic simulation SUMO, but count for other microscopic traffic simulations as well.

When benchmarking environmental measures, microscopic simulations promise some advantages over macroscopic ones. The first one is the greater detail of road layout and infrastructure representations. Traffic lights can be modeled including their real-world timings and/or the traffic adaptation algorithms they use. Other infrastructure units, such as variable message signs, can be replicated as well. This goes beyond the features of macroscopic simulations, because the measures used by present-day traffic light algorithms, such as the time headway of vehicles or counts of single vehicles, are not directly available therein. It should be mentioned, though, that these highly detailed representations come at the price of increased duration and costs for building an according simulation scenario.

The second advantage of microscopic simulations is the possibility of distinguishing between different types of vehicles. This allows reproducing regulations such as closing roads or restricting turns for heavy duty vehicles or prioritizing certain vehicle types at intersections. In conjunction with lane usage restrictions, the addition of dedicated public transport or HOV lanes can be modeled. In addition, modern ITS (intelligent transport systems) applications that use on-board vehicle devices that are not included in all vehicles can be evaluated. This is hardly possible using macroscopic simulations, because a) the macroscopically simulated traffic flow usually does not support different behaviors for individual vehicles it consists of, and b) an individual vehicle’s distinct position as given in the real world via GPS and often used by on-board applications is not given in macroscopic simulations either.

A third and probably the most important advantage is the availability of acceleration and speed profiles of all simulated vehicles for all simulation steps within microscopic simulations. These measures are the major input to so-called instantaneous emission models and are thereby crucial for a valid computation of pollutants emitted within a region.

One limit of traffic simulations is the lack of a modal choice model. As long as the demand can be assumed to stay constant after introducing the evaluated traffic management measure, microscopic traffic simulations are well suited to evaluating this measure. But many traffic management measures should be assumed to change the modal shares or – as in the case of advertising public transport, for instance – directly address such changes. Because the demand is an external parameter to traffic flow simulations, such measures cannot be replicated using traffic flow simulations only. Here, the inclusion of a proper demand model becomes necessary.

Microscopic Demand Models

For modeling large-scale areas, often so-called origin/destination (O/D) matrices are used. They describe the amounts of vehicles that leave an “origin” traffic analysis zone (TAZ) for travelling to a “destination” TAZ. Each cell of an O/D matrix contains the number of vehicles going from a certain origin to a certain destination zone within a predefined amount of time. Frequently, only a single O/D matrix is given for a whole day. This, however, evens out the daily changes in traffic directions, such as driving into the city in the morning and leaving it in the afternoon. For this reason, sets of matrices with a time aggregation of one hour should be used instead. Different vehicle type segments can be modeled using multiple O/D matrices per time interval, but such a disaggregation usually only distinguishes between passenger cars and heavy duty vehicles.

O/D matrices are often built using the four-step demand modeling approach (*22*). Roughly, this process can be outlined as follows. In the first modeling step, the demand generation, the number of daily trips expected to be conducted by a region’s population is computed based on statistics. Then, depending on the trip purpose, the locations of the activities are determined. In the third step, the mode choice – the selection of the transport mode to use – is performed. Given the so generated O/D matrices, the participants' routes through the road network are computed in the fourth step. While data about the size of the population is often available, the subsequent steps usually have to rely on samples (e.g. from interviews), models, and assumptions. The complete four-step approach results in road use measurements that can be set against available traffic counts for validation or calibration. (*22*) states that "*[a]lthough this approach has been moderately successful in the aggregate, it has failed to perform in most relevant policy tests, whether on the demand or supply side.*" Indeed, the coarse aggregation level seems to obstruct the view of possibilities to model a single road user's individual decisions.

A more modern approach for modeling the demand uses so-called agent-based or activity-based microscopic demand models (see (*23, 24*) for U.S. American primers). Instead of modeling the aggregate "population" for each TAZ, every road participant is modeled explicitly being described by a set of attributes, which at least include her or his mobility options. Within TAPAS (Travel Activity Patterns Simulation, (*25, 26*)), an agent-based microscopic demand model, all persons are characterized by their gender, age, budget, and employment status. Additionally, every modeled person holds information about having a driving license, a public transport season ticket, and/or a bike. Households are parameterized by their overall income and the available cars. They are allocated in the modeled region via their geo-coordinates.

Instead of computing each person's mobility needs and wishes by an internal model, TAPAS uses disaggregated diaries that stem from a pattern analysis of the German federal time use survey "Zeiterhebungsstudie 2002". After selecting one of the diaries that matches the person's attributes, activity locations and the modes of transport are determined. TAPAS supports Intervening Opportunities (*27*) and a gravity model (*28*) for location choice. The transport mode is selected using a multinomial logit function or a decision tree depending on the availability of correspondent data for the modeled region. The overall workflow of TAPAS is shown in Figure 1.

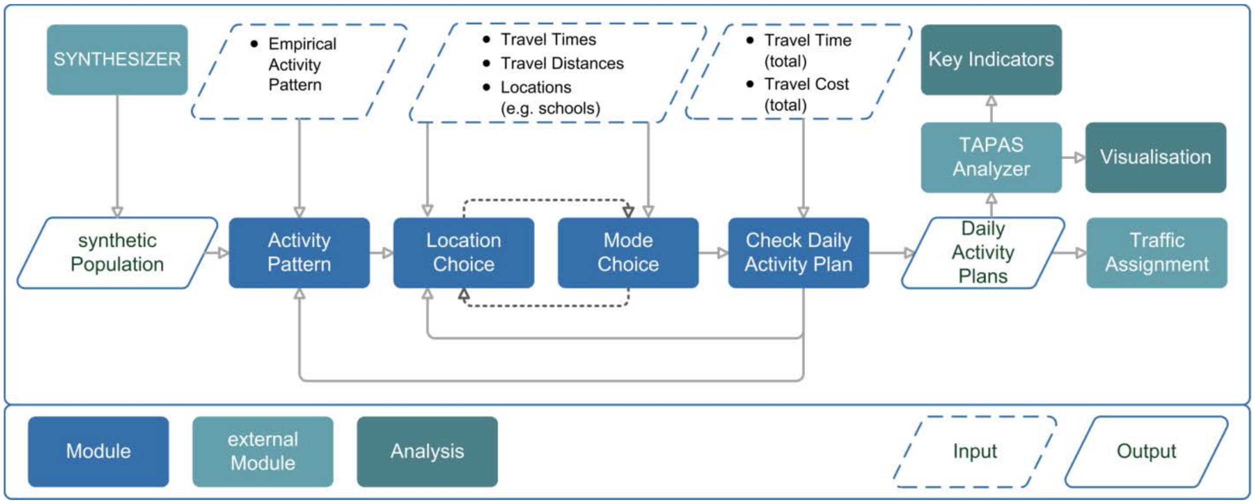

FIGURE 1 Workflow of activity plan computation in TAPAS (*29*).

In contrast to macroscopic demand models, agent-based demand models promise to be intrinsically sensitive to a large number of factors. Because all persons take into account their transport costs (vs. their budget), their mobility options, and travel times, a large variety of influences can be examined: regulative, such as tolls and vehicle bans; fiscal, such as changes in mobility costs or available budget; infrastructural, such as building or extending infrastructure facilities; and political, such as subsidizing emission-less vehicle types. The variability of such models' applications is already indicated by the vast number of possible evaluations of the results as depicted in Figure 2.

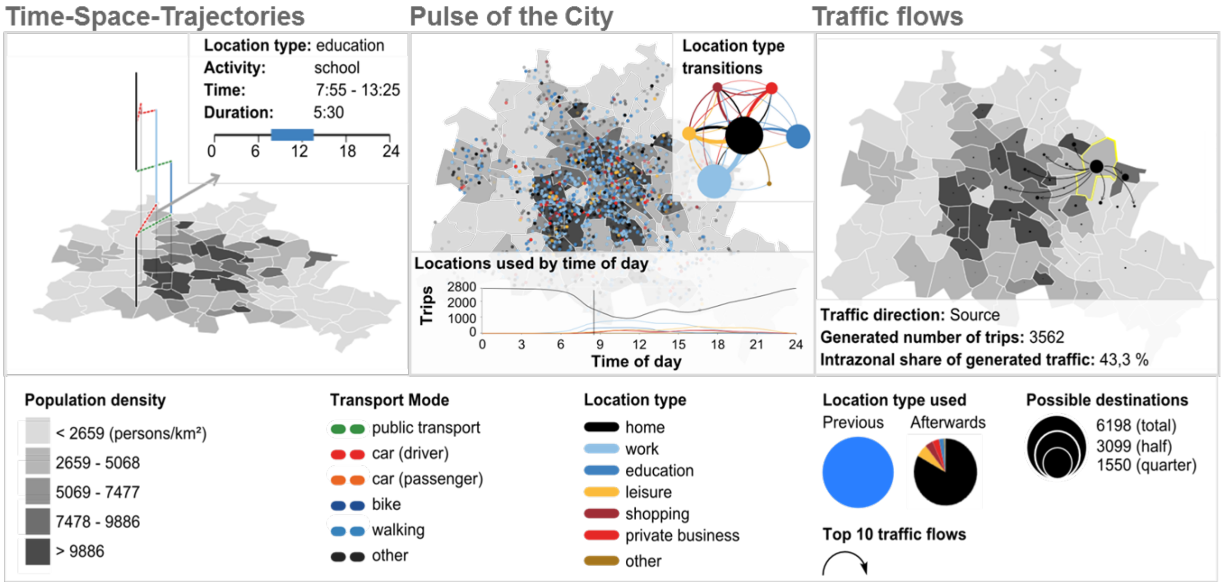

FIGURE 2 Some disaggregated and aggregated views at mobility patterns as computed by TAPAS; from left to right: a single person's journeys over a day, activities within the city (sample), aggregated O/D flows from a selected TAZ (*29*).

One more recent extension to agent-based demand models is the inclusion of models for households' car ownership that assigns typed vehicles to households (see e.g. (*30*)). The knowledge about the purchasing and according availability of vehicles of specific types extends the applicability of microscopic demand models. Given such a car ownership or car purchase model, the introduction of new technologies such as electrical vehicles or changes in fuel prices can be simulated. In combination with according emission models, the exact allocation of vehicles to households and subsequently to journeys should be assumed to improve the accuracy of the overall city model (*30*).

Embedded Instantaneous Pollutant Emission Models

As for traffic flow models, one can find different aggregation classes within emission models (*31*). Usually, they come with a corresponding coverage of the vehicle fleet: the finer the model, the fewer vehicle types are covered (*32*). Inventory models, such as European COPERT (*33*) or HBEFA (*9*), often compute emissions covering the – almost – complete vehicle fleet, but only use aggregated indicators, such as vehicle mileage and an abstract traffic state as input. On the other hand, several detailed so-called instantaneous emission models exist. They include different vehicle-specific attributes in their formulas, such as engine displacement, gear translations, or the vehicle's aerodynamics. Due to this large amount of model parameters they consequently cover only a few vehicle types. As a result, only a few models exist that are capable of representing a region's complete vehicle fleet at a microscopic scale, e.g. PHEM from the University of Graz (*34*), or VERSIT+ from TNO (*35*). These models are available as standalone applications which read vehicle trajectories and vehicle types and compute the corresponding emissions by virtually driving along the read trajectories.

Past tests have shown that using such standalone applications for computing emissions generated within a city-wide area is hardly feasible. The amount of trajectory data obtained from simulating a single day of a whole city is simply too big to be read into the application at once. Although possible, splitting this data into parts and reading it incrementally takes a very long time. The solution is to embed the emission model directly into the traffic simulation. The simulated vehicle's current acceleration and speed can be passed to the (internal) emission model directly for computing the emissions produced in the last simulation step. For city-wide evaluations, the individual instantaneous emissions can be collected and aggregated for each road, road segment, or area and within user-defined time intervals. Such a close coupling between the traffic flow simulation and the emissions model not only eases data handling but also allows each vehicle to be assigned to a certain emission class.

Two different emission models, both with proven applicability to large-scale scenarios (e.g. *13*) have been included into SUMO (*36*). The first model was generated by extracting the emission values for different speed levels and road slopes from HBEFA. A basic energy consumption function was fit to these values for obtaining a continuous function over speed and acceleration. The second model was developed by the Technical University of Graz by sampling emissions for certain acceleration and speed combinations from PHEM. The model obtained, "PHEMlight", uses so-called "Characteristic Emission curves over Power" (CEPs) that hold the information about the amount of generated pollutants, given the instantaneous power demand of the vehicle. The power demand itself is computed using the information about each vehicle's speed, acceleration and the slope of the road. Further attributes specific to the vehicle type, such as its weight or its aerodynamics are given in additional data files. PHEMlight has proved to be reliable by comparing it against original PHEM measures (*36*), which were matched against pollutant emissions from real-world vehicles (*34*).

SIMULATING TRAFFIC MANAGEMENT MEASURES

In a first step, a single dedicated city is being taken into regard. The city of Brunswick, a German city with about 300,000 inhabitants was selected for this purpose, because a well prepared simulation scenario for this city has already been set up (*37*).

When trying to determine which measure or which set of measures is the best for a given city, a comprehensive list of measures performed up to date one could select from would be of benefit. But an automatic processing of the 3,500 measures described in MARLIS is cumbersome due to their colloquial description in conjunction with an often reductive classification. MARLIS lists about 60 measures for Brunswick. They include ones that try to improve and advertise the public transport offer, ones that foster bicycle and pedestrian traffic, and ones that control and improve motorized individual traffic (MIT). A first and coarse attempt to determine the measures of interest is given in (*13*), but one should mention that this classification focusses on MIT due to relying on a traffic flow model only. Given a more comprehensive simulation system as described herein, which additionally includes an agent-based demand model and is thereby capable to replicate the users' mode choices, the list of measures to simulate should be revisited.

Given the tools introduced, the simulation process itself is quite straightforward. As usual, a base case representing the situation in the city without the introduction of a traffic management measure is simulated first. In a first step, the agent-based demand model TAPAS is applied for determining the mobility demand in the study area in the form of individual trip chains for every population member. These trip chains are read by the traffic flow simulation SUMO and an assignment is computed for obtaining the corresponding routes through the road network. When working with SUMO, often the iterative method developed by Gawron (*38*) is used for traffic assignment, but other options, including a “one-shot”, single step assignment (*39*) are supported as well. SUMO can load demands from multiple files within a simulation run, which can be used to set up public transport and service operations with fixed routes individually.

After performing the traffic assignment, the resulting individual routes through the road network can be simulated again for obtaining the desired measurements of the base case, such as emissions per road aggregated over time. This additional step helps to avoid the generation of large output files during the iterative assignment process itself. The complete workflow is depicted in Figure 3.

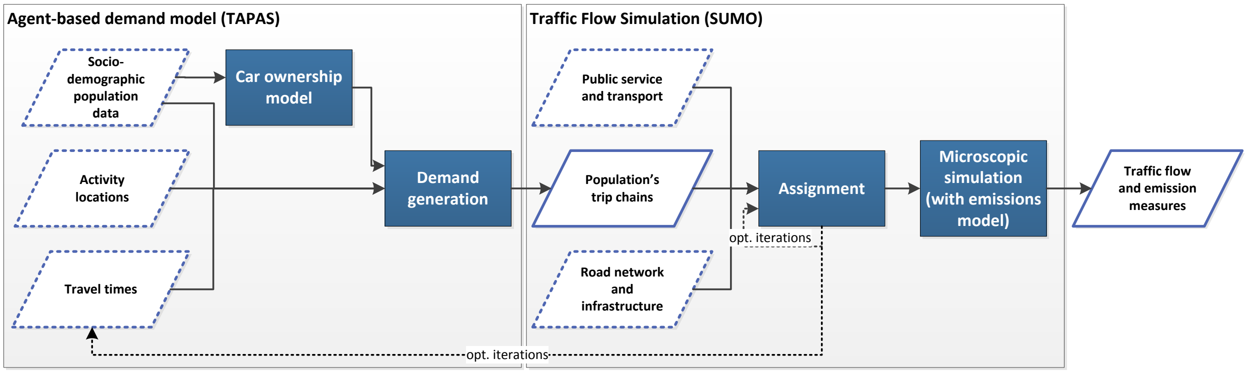

FIGURE 3 Workflow for computing the base case and subsequent scenarios when using TAPAS/SUMO.

The simulation of the traffic management measure being investigated is prepared in a similar way to the base case. Changes in the infrastructure, including the addition of new roads, restrictions of turns or road usage for certain vehicles, speed limits, as well as adaptations to the traffic light timings or algorithms have to be accordingly represented in a new version of the road network used. Measures that change the behavior of public transport or service operations have to be embedded in the corresponding inputs to the traffic flow simulation. Accordingly, such changes in the accessibility of public transport, its lines and schedules, as well as changes in the pedestrian, bicycle, or MIT infrastructure must be replicated in the travel time matrices used by TAPAS. The latter can usually be achieved using an iterative process only; after instantiating a measure that changes the modal shares and thereby the network load, travel times change as well. But this influences the users’ decisions about the transport mode to use. Thereby, it is often necessary to compute the effects of a measure iteratively, by supporting a new demand to the traffic flow simulation, first, and obtaining new travel times that are used for computing the population’s behavior in the subsequent step. This iteration ends when a stable state is reached, i.e. the travel time differences between subsequent iteration steps fall below a formulated threshold. It may be mentioned that up to now, no oscillation issues were observed. Afterwards, the assigned demand that reproduces the population’s behavior after instantiating the measure can be simulated again for computing the wished measurements.

APPLICATION EXAMPLES

In the following, results are presented from using the model chain described for simulating two exemplary traffic management measures. The chosen measures are the introduction of an environmental zone and a speed limit change from 50km/h to 30km/h within residential areas. They have been chosen, because they can be compared to earlier investigations reported in (*13*). As mentioned, the investigations reported in (*13*) relied on a traffic flow simulation only and ignored possible changes in the users' mode choice. Both examples are based upon the simulation of the city of Brunswick.

Environmental Zone

Within environmental zones (EZ), older vehicles with poor emission classes are disallowed. EZs are usually instantiated in inner-city areas. Although tolls and restrictions can be modeled for each TAZ in TAPAS, this in fact is not even necessary for simulating EZs, because given evaluations of the effects of introducing EZs show that the majority of the vehicle fleet is adapted by the population before the EZ is instantiated (*40*). As a result, no major effects on the mode or location choice appear and the introduction of an EZ can be simulated solely by accordingly adapting the simulated vehicle fleet. Figure 4 shows the changes in amounts of emitted NO_x per road.

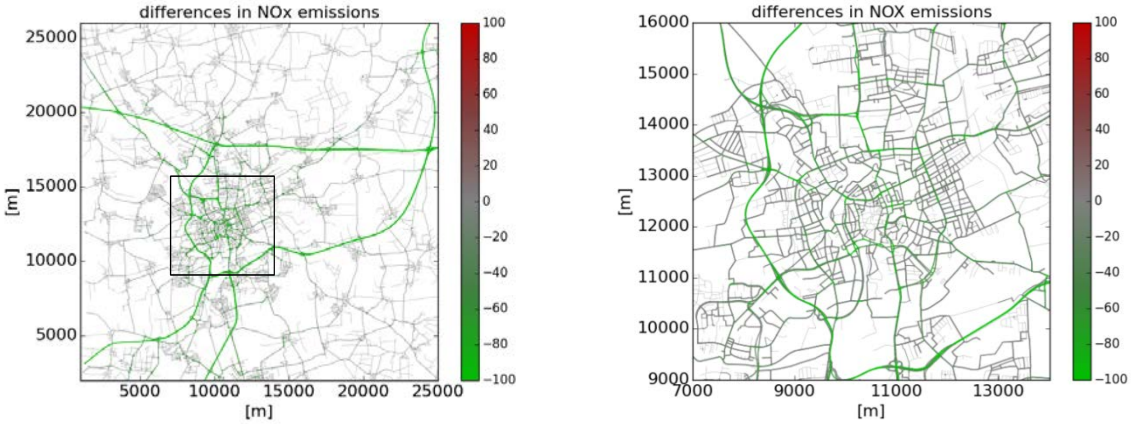

FIGURE 4 Differences in NO_x emission after introducing the environmental zone in g/km/h; left: complete simulation area, right: city center (indicated by a box in left image).

Because of the lack of changes in traffic demand, the benefits of using the described combination of simulators in a loop do not show their potential when simulating environmental zones. Here, using a microscopic traffic model in conjunction with an emission model is in itself a sufficient approach.

Tempo 30

In (*13*), the "Tempo 30" scenario was set up by selecting roads that were found to be within "residential" areas given in OpenStreetMap (*41*) data of this region. The maximum velocity allowed on these roads was set to 30km/h and a user assignment was performed. The demand was kept same as in the base case within (*13*).

With respect to inter-dependencies between demand and traffic flow, the Tempo 30 scenario seems to be more interesting than the introduction of an environmental zone. One should assume that because of longer travel times, a section of MIT users decides to use a different mode of transport. The results obtained using the described combination of SUMO and TAPAS confirm this expectation. As shown in Figure 5, fewer trips are performed using motorized individual transport, while the share of public transport, walking, and riding a bike grows.

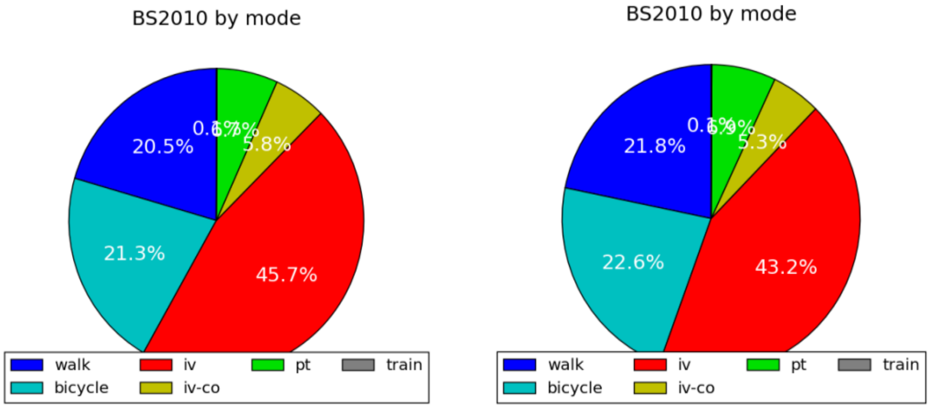

FIGURE 5 Modal split for the plain (left) and the Tempo 30 (right) case.

When looking at the environmental effects, this modal shift yields in less traffic (Figure 6, left) and in an corresponding reduction of emissions (Figure 6, right). This is contradictory to the results presented in (*13*) where the demand was not adapted.

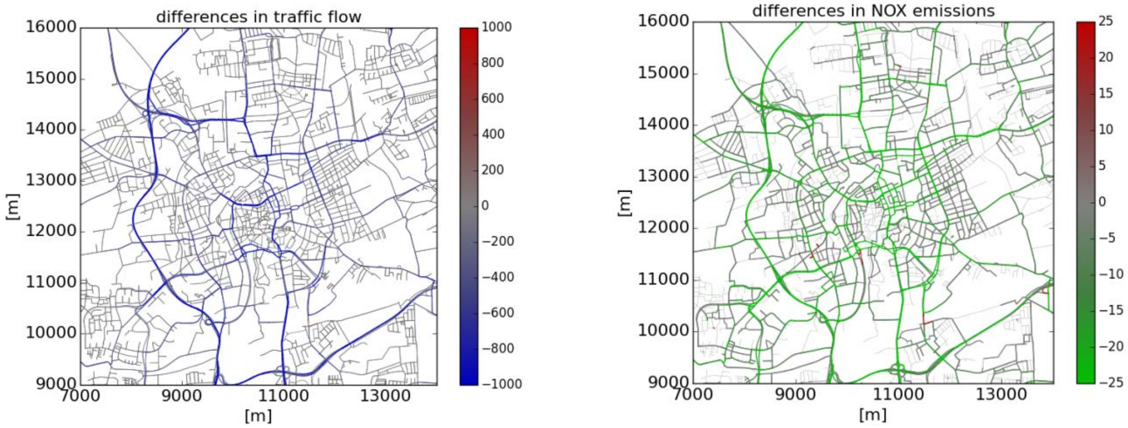

FIGURE 6 Effects of introducing speed limits; left: on the traffic flow in vehicles/day, right: on NO_x emissions in g/km/h.

SUMMARY AND OUTLOOK

The possibilities of using a combination of microscopic models for demand, car ownership, and traffic flow for a priori evaluations of city-wide traffic management measures that target improved air quality were presented. As discussed, present-day microscopic models can be employed for this purpose, extending the coverable use cases when compared to traffic flow simulations only, and allowing for very fine-grained investigations that macroscopic approaches do not support.

The presented microscopic simulation system is capable of delivering such fine-grained information about the road traffic's emissions and shows the global – in terms of the city area – effects of the simulated measure. Changes in the population's behavior, such as changes in mode and route choice are taken into regard. This allows for more comprehensive evaluation of a measure's effects than when using a traffic flow simulation only. The simulation system seems to be well-applicable for selecting a proper measure and to fine-tune it, if necessary.

The major requirements for successful employment of such microscopic models are a high execution speed and a low memory consumption for enabling the simulation of large-scale scenarios within a reasonable time. One crucial step to achieve this is to embed the emissions model into the traffic flow simulation for avoiding the exchange of large data amounts.

In fact, fine-grained demand models could be extended for being applicable to even more measures by increasing the number of influences that determine daily plans, locations, or transport modes. As such, the introduction of intermodal routes and car sharing are extensions performed currently. Further extensions to the overall system could include the addition of a pollutant dispersion model.

REFERENCES

1. Fenger, J. (1999) Urban air quality, *Atmospheric Environment* , 1999, 33, 4877 – 4900.
2. Mage, D., G. Ozolins, P. Peterson, A. Webster, R. Orthofer, V. Vandeweerd, and M. Gwynne (1996) Urban air pollution in megacities of the world, *Atmospheric Environment*, 1996, 30, pp. 681 – 686.
3. Vahlsing, C., and K. R. Smith (2012). Global review of national ambient air quality standards for PM_{10} and SO_2 (24 h). *Air Quality, Atmosphere, & Health*, 5(4), pp. 393–399, doi:10.1007/s11869-010-0131-2.
4. Marco, G., and X. Bo (2013) Air Quality Legislation and Standards in the European Union: Background, Status and Public Participation, In *Advances in Climate Change Research*, 2013, 4, pp. 50 – 59.
5. European Parliament and the Council of the European Union, Directive 2008/50/EC on ambient air quality and cleaner air for Europe, 2008.
6. Chiquetto, S. (1997) The environmental impacts from the implementation of a pedestrianization scheme, In *Transportation Research Part D: Transport and Environment*, 1997, 2, pp. 133 – 146.
7. Affum, J., A. Brown, and Y. Chan (2003) Integrating air pollution modelling with scenario testing in road transport planning: the TRAEMS approach, In *Science of The Total Environment*, 2003, 312, pp. 1 – 14.
8. Kickhöfer, B., Nagel K. (2013). Towards High-Resolution First-Best Air Pollution Tolls. In: *Networks and Spatial Economics*, pp. 1–24. DOI: 10.1007/s11067-013-9204-8.
9. INFRAS, *Handbook Emission Factors for Road Transport*, http://www.hbefa.net/, last visited on 31st of July 2015.
10. Hatzopoulou, M., J. Hao, and E. Miller (2011) Simulating the impacts of household travel on greenhouse gas emissions, urban air quality, and population exposure, In: *Transportation*, Springer US, 2011, 38, pp. 871-887.
11. Krajzewicz, D., J. Erdmann, M. Behrisch, and L. Bieker (2012) Recent Development and Applications of SUMO - Simulation of Urban MObility. In: *International Journal On Advances in Systems and Measurements*, 5 (3&4), pp. 128-138. ISSN 1942-261x.
12. Institute of Transportation Systems, German Aerospace Center (2014-2015) SUMO web pages, http://sumo.dlr.de/, last visited on 31st of July 2015.
13. Krajzewicz, D., N. Furian, and J. T. Vergés (2014) Großflächige Simulation von Verkehrsmanagementansätzen zur Reduktion von Schadstoffemissionen. In: *24. Verkehrswissenschaftliche Tage Dresden*.
14. Treiber, M., and A. Kesting (2014) Automatic and efficient driving strategies while approaching a traffic light, In: *IEEE 17th International Conference on Intelligent Transportation Systems (ITSC) 2014*, doi: 10.1109/ITSC.2014.6957838.

15. Krajzewicz, D., P. Wagner, M. Woelki, and M. Dippold (2015) Driving patterns reducing pollutant emission at traffic lights, acc. f. publ. in proceedings of the *22nd ITS World Congress*, Bordeaux, France, 5–9 October 2015.
16. Blokpoel, R., J. Vreeswijk, and D. Leistner (2012) Micro-routing using accurate traffic predictions, In: *Intelligent Transport Systems*, IET, 2012, 6, pp. 380-387.
17. Schneider, C., S. Turhan, A. Baum, and B. Surkus (2013) MARLIS - Maßnahmen zur Reinhaltung der Luft in Bezug auf Immissionen an Straßen; Kontinuierliche Dokumentation von Maßnahmen zur Luftreinhaltung; In: Bundesanstalt für Straßenwesen. *Kolloquium „Luftqualität an Straßen 2013"*, 2013.
18. AVISO GmbH. (2012) *Kurzinformation zur aktuellen MARLIS Version 3.0*, enclosed in MARLIS Version 3.0.
19. L. A. Pipes (1953) An Operational Analysis of Traffic Dynamics, In *Journal of Applied Physics*, 24, 274-281.
20. Chowdhury, D., L. Santen, and A. Schadschneider (2000) Statistical physics of vehicular traffic and some related systems, *Physics Reports*, 2000, 329, pp. 199 – 329.
21. Toledo, T (2007) Driving Behaviour: Models and Challenges, In: *Transport Reviews*, 2007, 27, pp. 65-84.
22. McNally, M. G. (2008) *The Four Step Model*. UC Irvine: Center for Activity Systems Analysis. Retrieved from: http://escholarship.org/uc/item/0r75311t
23. Zheng, H., Y. Son, Y., Chiu, L. Head, Y. Feng, H. Xi, S. Kim, and M. Hickman (2013) A Primer for Agent-Based Simulation and Modeling in Transportation Applications, FHWA-HRT-13-054, FHWA.
24. Castiglione, J., M. Bradley, and J. Gliebe (2015) Activity-Based Travel Demand Models: A Primer; TRB SHRP 2 Report S2-C46-RR-1.
25. Justen, A., R. Cyganski (2008) Decision-making by microscopic demand modeling: a case study. In: *Transportation decision making: issues, tools, models and case studies,* ISBN 9-78-88-96049-06-8.
26. Mehlin, M., A. Klein-Hitpaß, R. Cyganski (2011) Demographic Effects on Passenger Transport Demand. In: *ENVIRONMENT & POLICY Demography and Infrastructure, National and Regional Aspects of Demographic Change*, 51 (DOI 10.1007/978-94-007-0458-9). pp. 95-110, Springer, ISBN 978-94-007-0457-2. ISSN 1383-5130.
27. Stouffer, S. A. (1940) Intervening Opportunities: A Theory Relating Mobility and Distance, In: *American Sociological Review*, Vol. 5, No. 6, pp. 845-867.
28. Hua, C., and F. Porell (1979) A Critical Review of the Development of the Gravity Model, In: *International Regional Science Review Journal*, vol. 4, no. 2, pp. 97-126, DOI: 10.1177/016001767900400201.
29. Cyganski, R., A. von Schmidt, D. Teske (2015) Applying Geovisualisation to Validate and Communicate Simulation Results of an Activity-based Travel Demand Model, In: *GI_Forum 2015 – Geospatial Minds for Society*, (Abstract) Page 575, doi: 10.1553/giscience2015s575, ISBN-13: 978-3-87907-558-4, ISBN-13 Online: 978-3-7001-7826-2.
30. Vyas, G., R. Paleti, C. Bhat, K. Goulias, R. Pendyala, H.-H. Hu, T. Adler, A. Bahreinian (2012) Joint Vehicle Holdings, by Type and Vintage, and Primary Driver Assignment Model with Application for California, In: *Transportation Research Record: Journal of the Transportation Research Board*, 2302, 74-83.

31. Franco, V., M. Kousoulidou, M. Muntean, L. Ntziachristos, S. Hausberger, and P. Dilara (2013) Road vehicle emission factors development: A review, In *Atmospheric Environment*, 2013, 70, 84 – 97.
32. Krajzewicz, D., R. Nippold, O. Lazaro (2009) *iTETRIS Deliverable 3.1 – Traffic Modelling: Environmental Factors*, public deliverable of the iTETRIS project.
33. UNECE/EMEP Task Force on Emissions Inventories and Projections (2007) *EMEP/CORINAIR Emission Inventory Guidebook – 2007*, European Environment Agency.
34. Hausberger, S., M. Rexeis, M. Zallinger, and R. Luz (2009) *Emission Factors from the Model PHEM for the HBEFA Version 3*, Report Nr. I-20/2009 Haus-Em 33/08/679.
35. Smit, R., R. Smokers, and E. Rabé (2007) A new modelling approach for road traffic emissions: VERSIT+, In *Transportation Research Part D: Transport and Environment*, 2007, 12, pp. 414 – 422.
36. Krajzewicz, D., S. Hausberger, P. Wagner, M. Behrisch, and M. Krumnow (2014) Second Generation of Pollutant Emission Models for SUMO. In: *SUMO2014 - Second SUMO User Conference*, 15.-16. Mai 2014, Berlin, Deutschland. ISSN 1866-721X.
37. Bauer, S., E. Bretschneider, J. Rataj, an T. Schumann (2009) AIM – APPLICATION PLATFORM INTELLIGENT MOBILITY. In: *16th World Congress for ITS Systems and Services*, 21.- 25. September 2009, Stockholm.
38. Gawron, C. (1998). Simulation-based traffic assignment – computing user equilibria in large street networks. Ph.D. Dissertation, University of Köln, Germany.
39. Behrisch, M., D. Krajzewicz, P. Wagner, and Y.-P. Wang (2010) Comparing Performance and Quality of Traffic Assignments for Microscopic Simulation. In: *New Developments in Transport Planning - Advances in Dynamic Traffic Assignment*, Edward Elgar Publishing Limited, pp. 361-386, ISBN 978-1-84844-963-3.
40. Rauterberg-Wulff, A., M. Lutz, red. (2011) *Ein Jahr Umweltzone Stufe 2 in Berlin; Untersuchungen zur Wirkung auf den Schadstoffausstoß des Straßenverkehrs und die Luftqualität in Berlin*. Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz Berlin.
41. OpenStreetMap contributors (2015) *OpenStreetMap web pages*, http://www.openstreetmap.org/, last visited on 31st of July 2015.