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A flexible modelling and simulation system for environmental impact analysis in traffic planning

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Abstract

We present a prototype version of a modelling and simulation system for environmental impact assessment in the field of traffic and logistics. This software system supports the user in modelling and simulating the environmental impact of various changes to traffic systems. Our approach integrates object-oriented modelling techniques with geographic information system (GIS) technology. The heart of the system is an extendable model base containing complementary and competitive models for the domain of transport and environment.

1 Introduction

Information technology offers various opportunities for environmental impact assessment.[2] A broad range of software systems for computer-supported environmental impact assessment have been developed, such as database systems for the management of environmental data (e.g. EQUEL by Plank[7]), specific applications of geographic information systems (e.g. SAMBA by Boman[1]), or expert systems for ecological evaluation (e.g. EXCEPT by Weiland[8]). In addition, simulation techniques are widely used in environmental research to account for the dynamics of complex systems.

In the three-year research project MOBILE (Model base for an integrative view of logistics and environment), funded by the *Volkswagen-Stiftung*, we are developing a system for environmental impact assessment in traffic planning. It combines simulation techniques with geographic information system (GIS) technology. This software supports the user in modelling and simulating a class of systems which are characterized by coordinated transformations of objects in

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space and time (logistical systems). In contrast to traditional approaches, we consider ecological scarcity of resources and the responsibility of reducing environmental pollution as essential conditions for the design and control of logistical systems. This approach is also called *eco-logistics*. During the last years, we have developed several simulation models for *specific* problems in this field, e.g. for the environmental impact of just-in-time delivery and production strategies (Hilty[3]) or of measures concerning commuter traffic in crowded areas (Hilty[4]). The aim of the MOBILE project is to develop a *general* tool which supports the user in modelling and simulating traffic and transport systems in the conceptual framework of eco-logistics.

2 Classic transport modelling

The so-called classic (four-stage) transport model is a result from practice in the 1960s but has remained more or less unaltered despite major improvements in modelling techniques during the 1970s and 1980s (cf. Ortuzar/Willumsen[6]). We use this model to introduce some terminology and to contrast our own approach, which will be described in the next section.

The classic model is presented as a sequence of four sub-models: trip generation, distribution, modal split and assignment (see figure 1). The approach starts by considering a zoning and network system, and the collection and coding of planning, calibration and validation data. This data includes the demographic and economic structure of the area under study. Based on these data, the following four stages of the model are executed:

(1) The *trip generation model* estimates the total number of trips generated and attracted by each zone of the study area.
(2) The *trip distribution model* allocates these trips to particular destinations, thus producing a trip matrix.
(3) The third stage normally involves modelling the choice of mode and this results in *modal split,* i.e. the allocation of trips in the matrix to different traffic modes.
(4) The last stage requires the *assignment* of the trips by each mode to the networks they use.

A first approach to account for the environmental impact of traffic systems is simply to extend this sequence by two or three additional stages (see figure 2):

(5) An *emission model* calculates the pollutants emitted by the vehicles, depending on traffic flow and traffic condition.
(6) An *immission model*, e.g. an atmospheric dispersion model, calculates the concentration of each pollutant as a function of space and time, depending on emission and weather data.
(7) An *evaluation model* can be used to aggregate such indicators of environmental pollution to a single pollution index.

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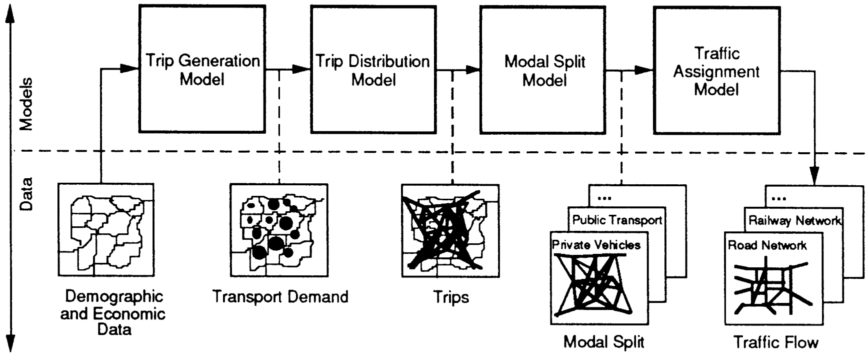

Figure 1: The classic four-stage transport model

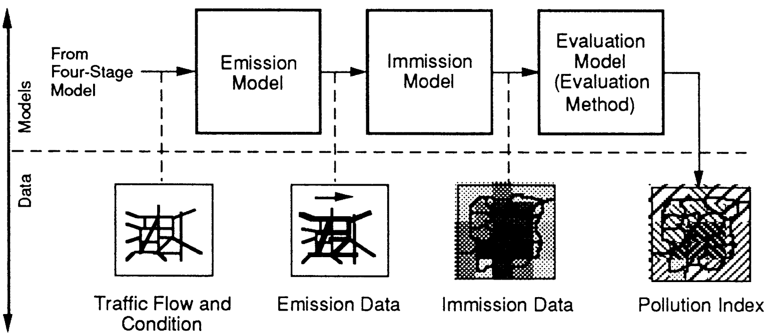

Figure 2: Extension of the classic model by three additional stages

However, such a „linear extension" of the classic model would not provide enough flexibility to model the complex behaviour that can occur as a result of interactions between the different stages.

3 Modelling transport with the MOBILE system

In order to provide maximum flexibility, the MOBILE system is designed to be a „construction set" for models. In contrast to commercial software, there is no „one and only" transport or environment model embedded in the program. Rather, the user is encouraged to build his own model by selecting and composing sub-models as building blocks from the model base. These building blocks cover a broad range of aggregation levels, perspectives, and problems in the field of transport and environment. This includes the linear sequence of seven sub-models shown in figures 1 and 2 as a special case.

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The model base includes complementary as well as competitive models. The possibility to compare competitive models is especially important in a field like transport modelling, where there are many different theories and views of the same phenomena. For example, there are at least 18 basic types of private transport assignment models (stage 4 in the classic model), depending on the assumptions made

- about the speed-flow relationships of network links and nodes (capacity restraint can be ignored or modelled on a macroscopic or microscopic level),
- about the route choice behaviour of the drivers (deterministic or stochastic behaviour model, travel time and/or other aspects included in the cost function),
- about the system being in a stationary or transient state (static or dynamic assignment).

Note, however, that assignment is not the most controversial aspect of transport modelling.

Comparing competitive models can be especially useful when it appears that they all lead to the same conclusion with regard to the investigated questions. Such simulation studies offer good support for argumentation, especially in discussions about the environmental impact of measures in the traffic sector.

In order to support the evolution of theories and models in the field of transport and the environment, the model base can be extended whenever the user wants to include a new model. The models are organized by means of structured metadata. We use metadata

- to guide access to the models available in the model base,
- to help the user to create reasonable model compositions (syntactic and semantic compatibility checks), and
- to support the user in model validation, especially in detecting sensitive data and sensitive sub-models.

Another important feature of the MOBILE system is the MOBILE script language (MSL), an object-oriented specification language for model compositions and simulation experiments. This language has a textual and a graphical notation. The latter does not contain all the details necessary for executable specifications and is used to sketch model compositions and experiments. The system automatically asks for missing information when an MSL specification is to be executed.

Figure 3 shows an example of an experiment specification in graphical MSL. Rectangles with double base lines represent (model) classes, whereas the boxes with smoothed edges depict instances. Simple rectangles are used to depict data included at instantiation time (e.g. Topology of Traffic Network). The data processed at runtime flow from sources (e.g. Traffic Demand) through instances (e.g. Assignment Model) to „sinks“ (e.g. Emission Maps).

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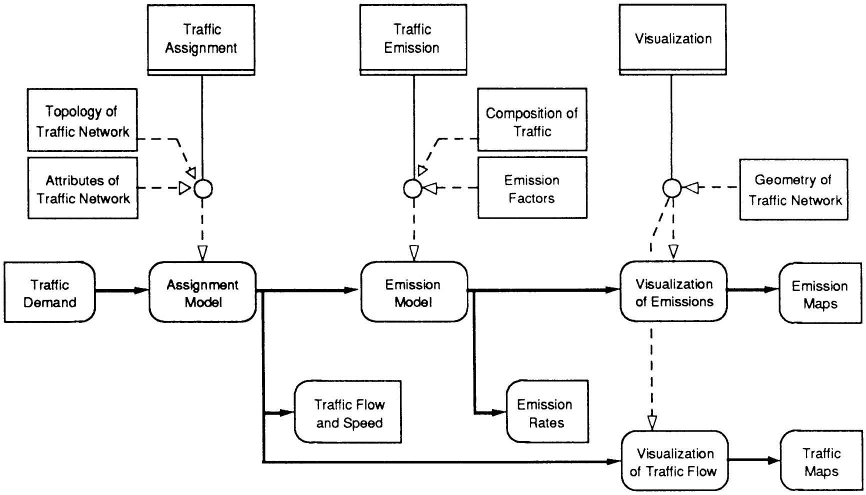

Figure 3: The graphic specification of a simulation experiment coupling an assignment and an emission model with a visualization method. When the experiment is executed, the models and the method are instantiated from their respective classes using the instantiation parameters. In the case of the assignment model these are the topology of the underlying road network and attributes such as road type, number of lanes and maximum speed for each link. The assignment model then computes traffic flow and speed from the input transport demand, passing this data to the emission model and an instance of the visualization method. The emission model provides emission rates which are dependant on the composition of the traffic, pollutant-specific emission factors and the average speed of the current flow. Finally, the results of both models are transformed into thematic maps by the visualization instances. Figures 5 and 6 show examples of such maps.

4 Architecture of the MOBILE system

The system architecture is sketched in figure 4. The most important part of the system is the *model and experiment base system*. The model base contains basic simulation models which can be composed to more complex models, tailored to the actual problem the user wants to study. The experiment base stores and organizes explicit specifications of the simulation experiments carried out so far in order to assure reproducibility and systematic variability of experiments.

The model and experiment base system is supported by the *data and method base system* which organizes the data and data transformation methods (e.g. statistical methods, visualization methods) used in simulation experiments.

Another important component is the integrated *geographic information system* (GIS) which supplies spatial data and is used to visualize traffic and environmental data in the form of thematic maps.

The MOBILE script machine (MSM) compiles and executes specifications written in the MOBILE script language (MSL) mentioned above.

The system offers different interfaces for two types of users:

- To the user working with existing traffic and environment models (the model user for short), the system is presented as a Dynamic Geographic Information System (DGIS). He or she can compose complex simulation models by combining basic building blocks from the model base and relating them to spatial data.
- To the user who wants to develop new models (the model builder for short), the system is presented as a flexible object-oriented modelling and simulation environment based on mathematical systems theory. Heterogeneous simulation models such as models with multiple aggregation levels (multi-scale models) can be realized.

Of course, the same person can act in both roles (model user and model builder) at the same time.

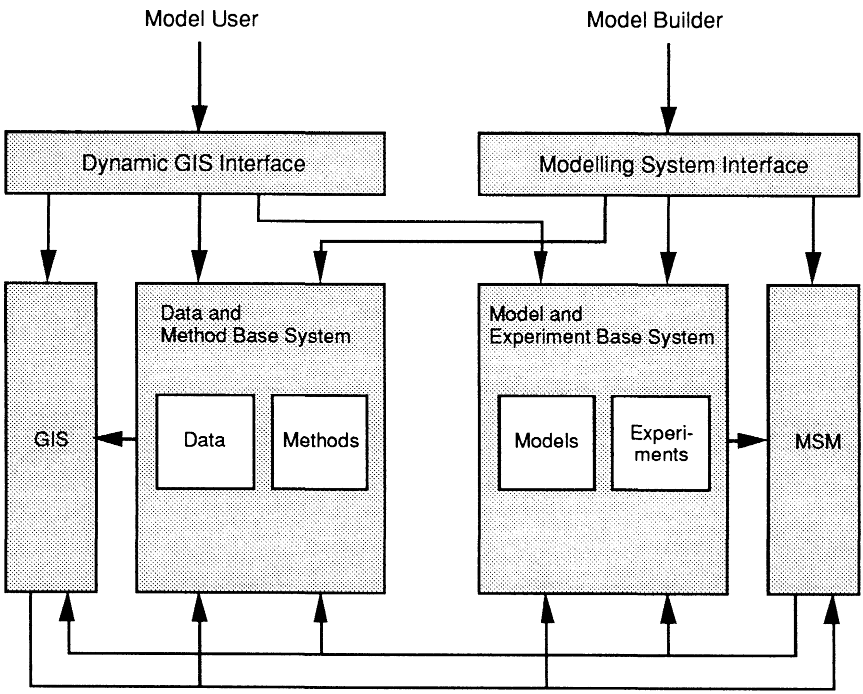

Figure 4: The MOBILE system architecture

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Finally, we want to show an example of the application of the MOBILE system. The question of this case study was, whether or not a planned bypass will reduce the traffic load and pollution in Finkenwerder, a region in the south of Hamburg which is heavily affected by growing commuter traffic.

Figure 5 shows the simulated traffic flow for two scenarios, the status quo and the situation after the bypass is built and the road in the north (presently used as a throughfare) is closed. The comparison shows that the situation in the north-east becomes even worse. This can be explained by the fact that some inhabitants of Finkenwerder are now forced to go a roundabout way. Figure 6 shows how the different traffic flow and traffic conditions affect the emission of nitrogen oxide (NO_X) by the vehicles.

Note that we simulated the temporal behaviour of traffic flow and pollution in this case study, and that the maps only show a snapshot at 8:00 a.m., when the commuter traffic flow is just passed its maximum.

The simulation experiment which was executed to produce these maps for one scenario is depicted in figure 3. The Traffic Maps and Emission Maps indicated on the right hand side of figure 3 correspond to the pictures shown in figures 5 and 6, respectively. The models used in this case study, assignment and emission model, correspond to stages 4 and 5 in the model sequence described in section 2. This „two-stage" experiment is a relatively simple case and was discussed here only for the purpose of illustration. In fact, the case study involved two competitive assignment models (which lead to the same results), emission models for different pollutants and an atmospheric dispersion model.

5 Conclusion

We presented a modelling and simulation system for environmental impact assessment in the field of traffic and logistics. Our approach to transport modelling as reflected by the MOBILE software system differs in three aspects from classic approaches:

1. Various traffic models and environmental models are available in the model base and can be connected by means of a high level specification language.
2. The model base includes complementary as well as competitive models, i.e. models which incorporate different hypotheses about the nature of the respective real system.
3. Model compositions as well as simulation experiments can be specified graphically.

The MOBILE system is still evolving and will be fully operational at the end of the project in 1997.

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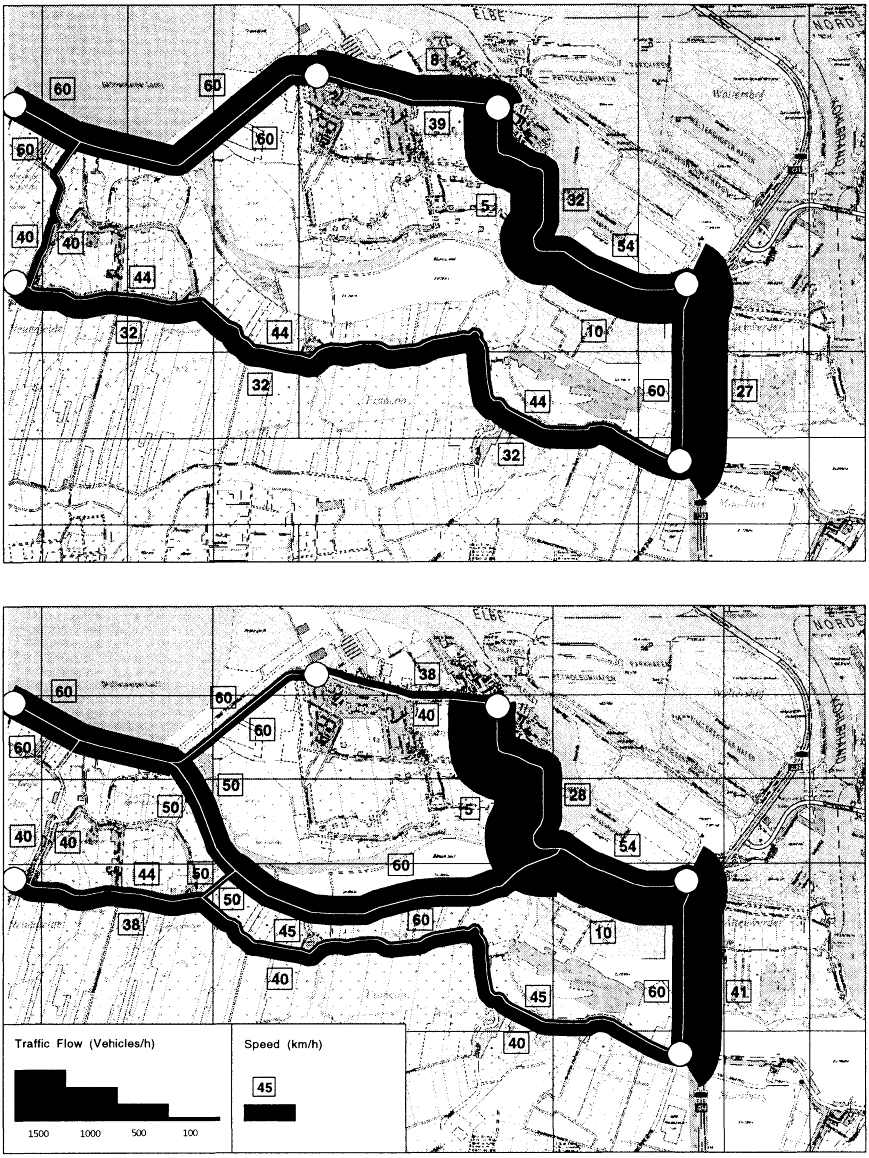

Figure 5: Traffic flow and average speed of the road traffic in the Finkenwerder region (a suburb in the south of Hamburg), calculated with a traffic assignment model on a normal working day at 8.00 a.m.; the situation in status quo (above) and after the building of a bypass with simultaneous closure of the centre for through traffic (below). The traffic flow and speeds are indicated separately according to direction.

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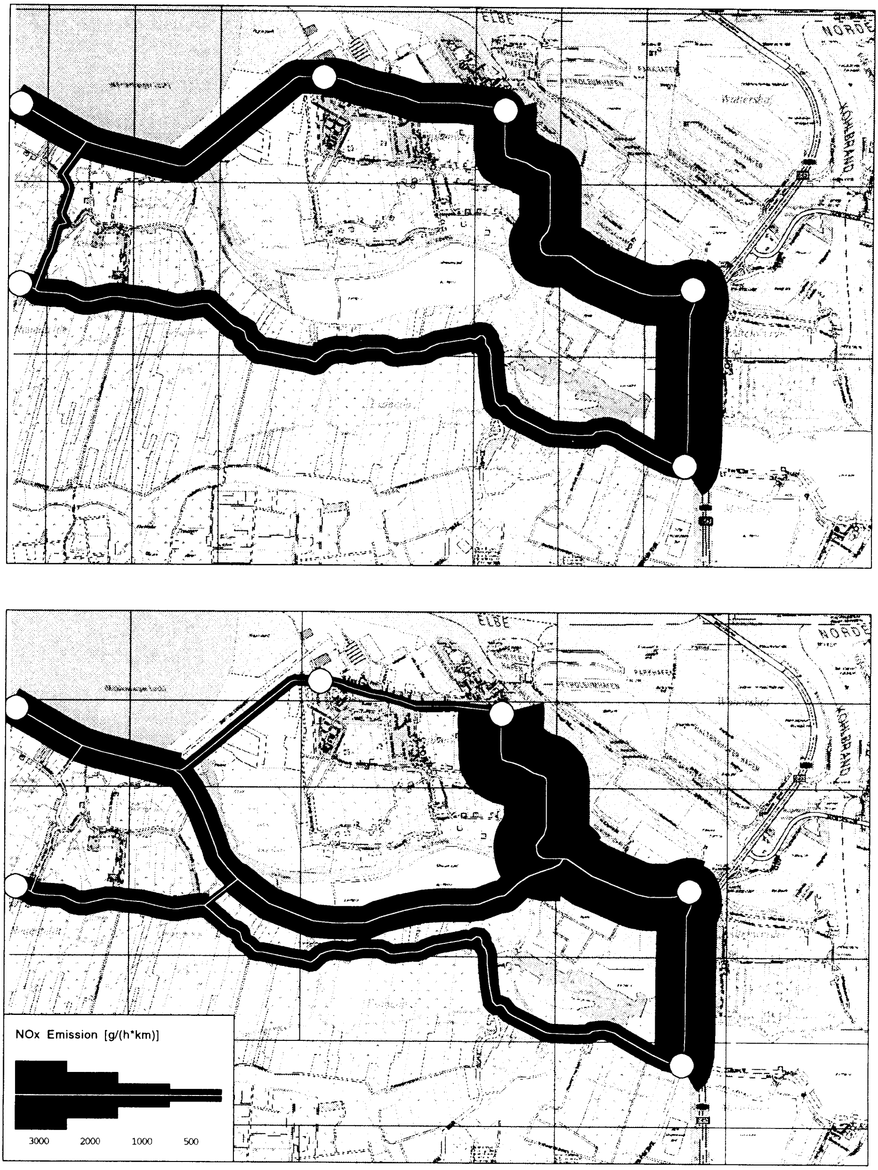

Figure 6: Emission rates of nitrogen oxide for the traffic flow and speeds given in Figure 5, calculated with an emission model. The proportion of trucks was assumed to be 5 %, the mix of car types and emission reduction techniques according to the national average. The emission rates from both directions were added together.

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