Urban Land Use, Transport and Environment Models

Experiences with an Integrated Microscopic Approach

Peter Wagner and Michael Wegener

Dr. Peter Wagner is head of the Traffic Surveillance Division of the German Aerospace Center in Berlin.

Professor Dr.-Ing. Michael Wegener is a partner of Spiekermann & Wegener, Dortmund, specializing in urban and regional research, and former Executive Director of the Institute of Spatial Planning, University of Dortmund.

Abstract: This paper gives an overview of the ILUMASS project (2002–2006) funded by the German Federal Ministry of Science and Education. The objective of ILUMASS was to implement a fully microscopic model of urban land use, transport, and environment (LTE). Considerable progress was made in developing and testing individual microscopic models and the interfaces between them. However, for several reasons, the planned application of the full model system for the simulation of policy scenarios was not achieved. Possible reasons for this failure are analyzed and recommendations are made to improve future interdisciplinary projects of this kind.

1. *Introduction*

Planning for sustainable land use and transport requires an integrated view of the two-way interaction between land use and transport. The challenges cities are facing can no longer be dealt within the limited view of a single profession. An interdisciplinary approach is needed which integrates land use policies with transport infrastructure development and traffic operation, as well as soft policies working with information or incentives. Only this integration will lead to a new, more balanced view of the entire urban planning process (see Mühlhans, Strauch 2005).

This is especially true when different developments overlap in space and time. The evolution of urban land use and transport and the environment is the result of a large number of decisions and actions of different actors, such as individuals, households, landlords or firms. The acceptance of planning policies by these actors determines the success of planning. Since individual decisions are important for the efficacy of planning, their actions should be taken into account. This is exactly the strength of microscopic models such as ILUMASS (see Mühlhans, Strauch 2005; Miller 2006).

The first generation of aggregate integrated models of urban land use and transport already made it possible to regard land use and transport effects together (Wegener 2004). This was a big step forward compared to travel demand models in which land use development was assumed to be exogenous. The important advantage was the ability to model the influence of the transport system on space, usually in the form of spatial interaction or accessibility models. While most firms are interested in having good traffic connections, most households wish to live in detached single-family houses in pleasant natural environments, which is the reason for suburbanization and urban sprawl.

The second important contribution of ILUMASS was to model both urban land use and travel and goods transport microscopically. While this is already common in the simulation of traffic flows, it is still not common practice in travel demand modeling, and even less so in land use modeling (Strauch et al. 2005; Wegener 2004). With this objective, ILUMASS is one of several similar projects in North America and Europe, such as ILUTE (Miller 2001; Miller et al. 2004), TLUMIP (Weidner et al. 2006), ALBATROSS (Arentze, Timmermans 2000, 2004), PUMA (Ettema, Timmermans 2006) and the IRPUD model (Wegener 1998; Spiekermann, Wegener 2007).

2. *Goals of ILUMASS*

A detailed description of the ILUMASS model is available as a technical report (Beckmann et al. 2007). The ILUMASS model is divided into the three modules referred to above: land use, transport and environment (see Figure 1). Each of these modules consists of several microscopic submodels:

Land use

The land use module is based on the one developed at the Institute of Spatial Planning of the University of Dortmund (IRPUD). However, the macroscopic models of the IRPUD model were rewritten in microscopic form for ILUMASS. The microscopic land use submodels include the following most important components:

• Population: The population model simulates the development of persons and households. In each year, all persons get one year older and, depending on their age and sex, have a certain probability to die. Couples move together and establish a new household, households become smaller as persons die, children leave or partners separate. Women give birth to children, depending on their ethnic background and age and whether they live together with a partner or not. Young people move together and establish non-standard households. In the population submodel, changes in employment are also modeled.
• Firms: As with persons and households, firm lifecycles are modeled in a microsimulation of foundation, growth and eventual relocation, decline and closure. The simulation of firm lifecycles is, in analogy to demography, called firmography. Firmography includes the simulation of new establishments, growth, decline and closure of firms. Firmographic events are modeled by transition probabilities subject to exogenously provided economic structural change and business cycles. Firmographic events may lead to relocations of firms.
• Residential mobility: The residential mobility submodel models location and housing decisions of households that move into, out of or within the region. Moves are modeled as transactions of households and landlords on the regional housing market. The attractiveness of a dwelling for a household is a weighted aggregate of the attractiveness of its location, quality and rent or price in relation to the household's housing budget. If the offered dwelling promises a significant improvement in housing satisfaction compared to the present dwelling, the household accepts the dwelling. Otherwise, it continues its search until it finds a suitable dwelling or abandons the search until the next year.
• Firm location/relocation: The second part of the simulation of firms simulates location or relocation decisions of firms. Firms dissatisfied with their present location examine up to ten alternative locations with respect to accessibility, size, price, quality and image and select a location if it offers a significant improvement of location satisfaction. Otherwise, the firm keeps its present location and may start a new search in the subsequent year.
• Residential buildings: The residential development submodel simulates investment decisions of private developers to demolish, upgrade or build residential buildings for rent or sale as a function of supply and demand on the housing market and profitability expectations. If the developer believes that positive returns can be achieved by upgrading or new construction, investments projects are planned. For each project, a zone and a microlocation (raster cell) are selected from the land zoned for residential use in the municipal land use plans subject to location criteria, such as accessibility, neighborhood facilities, environmental quality and land price. The projects are executed in the implementation phase.
• Non-residential buildings: The model of non-residential development examines the demand for floor space in each zone and develops new floor space in zones in which the vacancy rate is low. Floor space development is constrained by land use restrictions in the municipal land use plans. Within a zone, microlocations (raster cells) close to existing firms are developed before isolated locations. Newly developed land is immediately designated as built-up land, but the new floor space is only offered on the market one year later, in order to take construction time into account.

The land use modules provide input data for the origins and destinations considered in the transport submodel.

Transport

The transport module models the daily activities of people and, based on this, the demand for travel between different parts of the city at different times of the day and the demand for freight travel, as well as the resulting traffic flows. The travel submodel is a very detailed agent-based model that takes the needs and wishes of people to conduct activities and the resulting need for travel into account. Since the first fully microscopic version of the travel model turned out to be too complex to be run together with the rest of the model system, a somewhat simpler version was used. Even that simplified version needs considerable computing time as it computes a separate origin-destination matrix for every hour of the day. The demand generated by the travel and freight submodels was coupled with a microscopic dynamic traffic assignment model calculating traffic flows, link loads and travel times.

The transport module consists of four different programs. The first and most complex one is a psychological actor model for the synthetic population living in the study area. Based on socio-demographic data of each person, it computes a weekly activity plan by considering 29 different activities grouped in four main groups (personal, job and school, social activi-

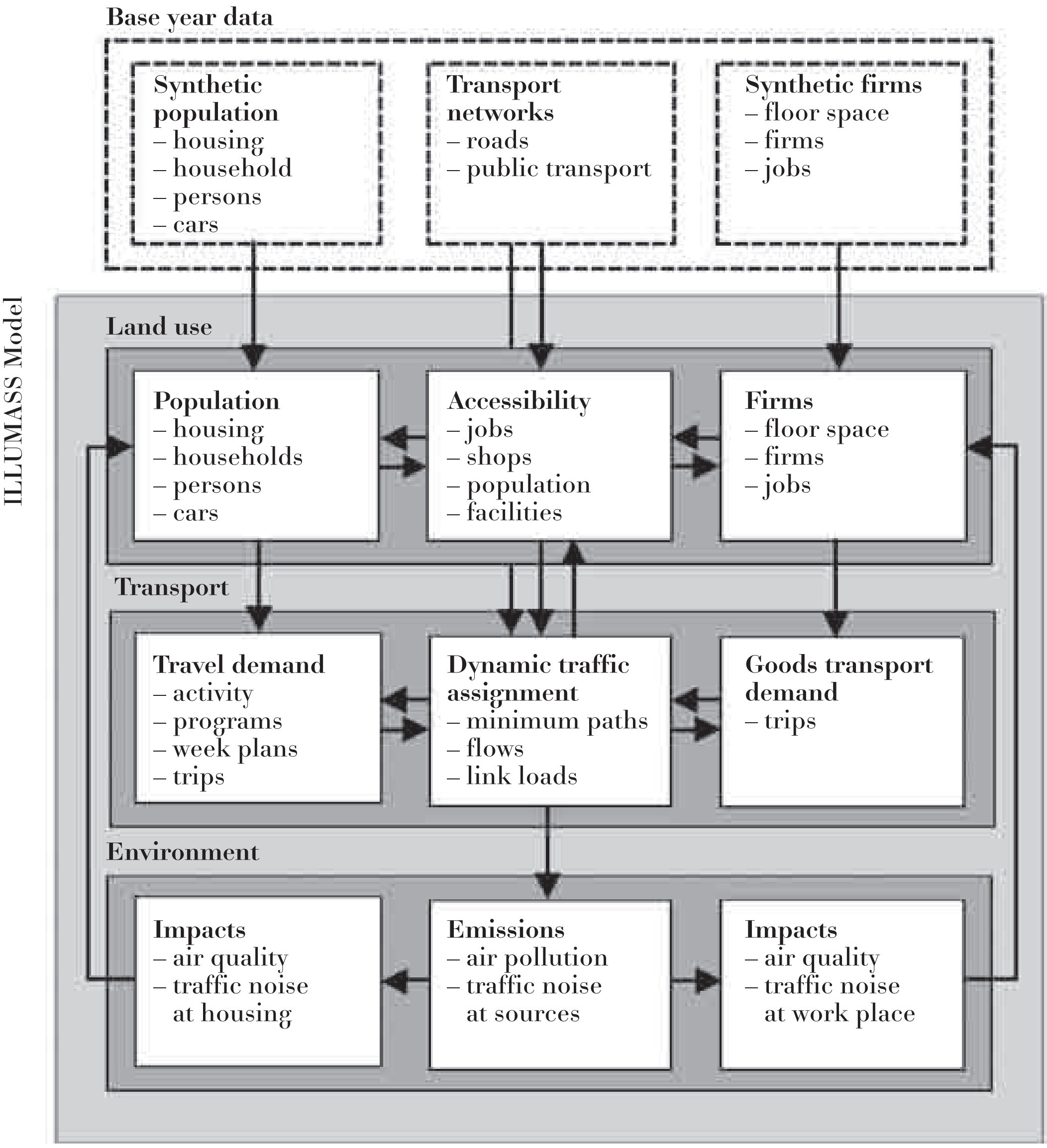

Fig. 1: Modules and submodels of ILUMASS.

ties, leisure). Such an individual plan contains a sequence of activities, together with information on whether this activity is at home or not. When not at home, a trip to a place where this activity can be performed is needed. These places have been named "opportunities". In addition, this demand model selects the place (it takes into account the capacity of the opportunity, e.g., it counts how many people can sit in a cinema and makes it less attractive if it becomes too crowded), the travel mode (based on availability of vehicles in a household context, and the current travel times, which are either that of the empty net or are the result of the microsimulation of traffic), and the departure time. This module can compute about one activity plan in one second computing time, so for the 2.6 million people in the study area, about two weeks are needed to complete the calculation of all the activity plans.

The route is then computed by a microscopic dynamic traffic assignment. This is a variant of the method described in Gawron (1998), and it iterates a shortest-path computation for all of the 2.6 million people with a subsequent microscopic simulation until equilibrium has been reached. The travel times are then used in the demand module and the additional traffic information, such as flows and speeds, are used in the environment module.

The demand generation for good transport was generated by a model that uses macroscopic data (input-output matrix of the German economy), together with a recent German survey on goods transport, to assign goods flow between the different companies in the city. The generated demand was used as additional input into the microscopic simulation above.

Finally, in a later stage of the project, a more traditional demand generation algorithm has been included in ILUMASS to partly overcome the difficulty with the long computing times needed by the psychological actor model. Different from traditional models, it uses a very disaggregated approach to a compute 24 hourly origin-destination matrices for the study area. Interestingly, the demand generation was still the slowest of the modules in ILUMASS. This is due to the fact that the search for the best opportunity for a given activity needs a very long time if the spatial disaggregation is made very fine, which was the case here.

Environment

Finally, the environment module models the environmental impact of traffic forecasts: CO_2 emissions and the distribution of air pollution, traffic noise, boundary layer effects (smog), and the barrier effects of traffic. The submodels apply state-of-the-art emission, air quality and noise propagation techniques based on a spatial grid of 352 000 grid cells of 100 x 100 m size. The environmental impact of traffic by vehicle category (lorry, car, bus), volume and speed are calculated as trajectories over a full week.

The calculated environmental impact is then fed back to the land use module; there they influence the location choices of land use agents because they affect the quality of locations. This closes the iteration loop of ILUMASS.

2.1 Data

Integrated models of urban development need very detailed spatial, land use, socio-economic and transport data. A microscopic model increases the demand for high-quality spatial data. Therefore, data management with a geographic information system (GIS) was important for the integration of the ILUMASS modules.

The ILUMASS model describes the dynamic evolution of the study area. Two distinct time scales can be recognized: the simulation of traffic and the demand for transport typically covers a time scale from seconds to weeks, while the land use develops over a much longer timescale, from months to years. From the point of view of modeling, this is fortunate because it separates the dynamics: while the transport system reaches its equilibrium within days, its results can be used as static input into the land use module. The output of the land use module, however, can then be used in a quasi-static way as the input to the transport module of the next simulation period, which was one year for ILUMASS. It was a working hypothesis that the simulation of transport on such a short time scale (instead of using average daily traffic as it results from a traditional traffic model) is important for modeling human mobility behavior.

To model individual activity patterns, it was necessary to have the model population available on a per person basis. As microscopic person and household data were not available, this was achieved by the generation of a "synthetic" population, in which the number of agents with the same statistical features corresponds to that of the real population (see Moeckel 2004).

The synthetic population is updated annually in the land use module and used as input to the transport module. The travel demand submodel uses the synthetic population to generate individual activity programs for each mobile person based on person- and group-specific activity repertoires. These activity programs are aggregated to trip tables by origin and destination and time of day. This travel demand is then converted to traffic loads on the network in the dynamic traffic assignment submodel.

Using spatial data needs a spatial co-ordinate system. In ILUMASS, three levels of disaggrega-

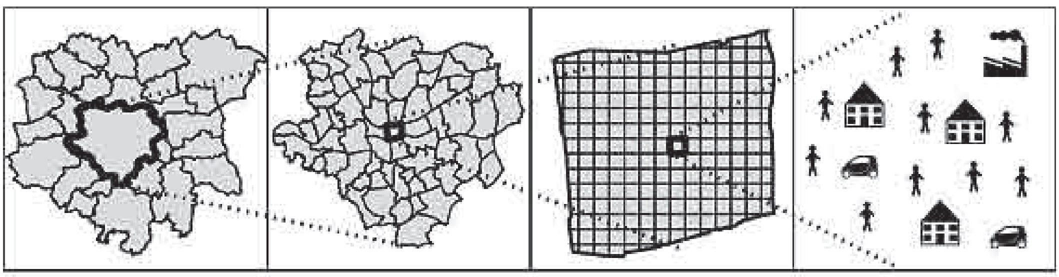

Fig. 2: Macro-, meso- and micro-spatial resolution (Schwarze et al. 2004).

tion were distinguished: micro, meso and macro (see Figure 2). For the smallest spatial unit, a grid cell of a 100 by 100 m size was used. The whole study area was divided into 352 000 of such cells. The co-ordinates of each cell were used as the locations of agents and other objects (firms, houses or other destination activities). Although it would have been possible to go to an even more disaggregate spatial scale, for reasons of practicability, it was decided to stop at this resolution. The other two levels define traffic analysis zones for additional demand generation (meso) and municipalities in the Dortmund urban region (macro).

2.2 Simulation and feedback

A model run of ILUMASS begins in the year 2000. It starts from the socio-demographic and spatial structure and generates from this the demand for transport, travel and freight transport and then the environmental impact of transport. These are then fed into the land use model for the following year, which generates a new socio-economic and spatial structure, which is used again as input to the transport module of the following year. In this manner, the state of the year 2000 is "transported" into the future. By defining different scenarios that represent different policies, different trajectories of system evolution can be traced and subsequently analyzed for their effectiveness. This can help to identify successful and less successful policies at an early stage and to find better ideas on how the system can be optimized.

In the first year, the traffic simulation is similar to a classic four-stage travel demand model. After the first year, the feedback described above sets in and generates the fully dynamic evolution (see Figure 3). Within one simulation period, there is a direct interaction between the travel demand and traffic simulation: the traffic simulation returns travel times to the route choice submodel, which tries to drive the simulation to user equilibrium by assigning new routes to the simulation until it is in equilibrium, or, if this fails, asks the planner (the demand generation tool) to re-plan the activity programs of agents that do not have a feasible activity plan. This step guarantees the consistency of the model

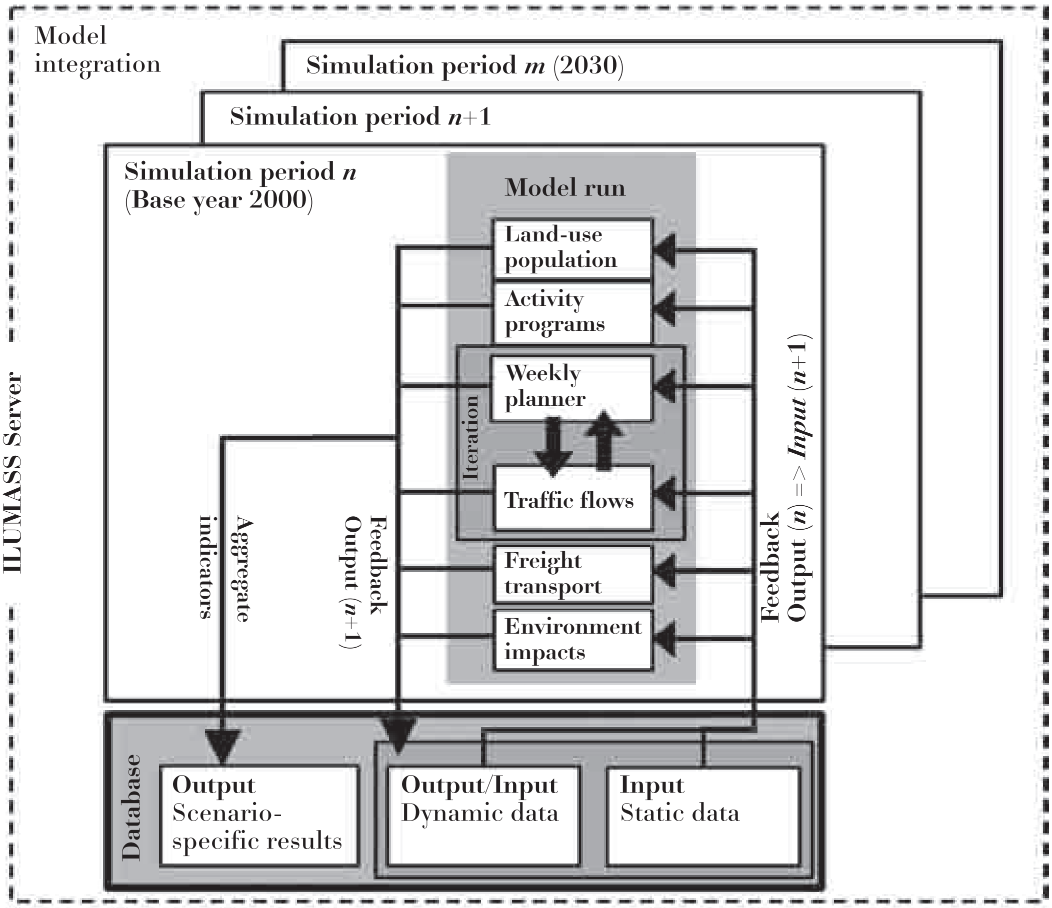

Fig. 3: Integration and data management in ILUMASS (Mühlhans, Strauch 2004).

because, otherwise, the planning of the agents would be unconstrained and could include unrealistic plans. The travel times used in the planning of the agents should be in line with the true travel times in the network.

As the system proceeds from year to year, the feedback between transport and land use is affected. After each simulation period, the following data are available:

- Population, households, employment, firms, residences and industrial and commercial floor space and land use data by grid cell, traffic analysis zone or municipality.
- A fully disaggregated demand for transport, defined as trips from grid cell to grid cell by time of day or summarized in origin-destination matrices by mode of transport.
- Detailed information about network travel times from the traffic flow simulation, as well as traffic loads on each link of the network.
- An approximation of the demand for freight transport and business travel computed by the freight transport submodel.
- Transport-generated air pollution, noise and other emissions for each grid cell, computed by the environment module.

3. Integration and data management

The data management distinguishes static and dynamic data. Static data already exist before the start of the simulation; they are not modeled. Examples are the road networks, land use plans, factors that describe human behavior and the various emission factors. Over the course of the simulation, dynamic data changes because it is generated by the simulation itself. The changes are important for the feedback between the simulation modules. Results that are relevant for later analysis are aggregated and stored. A dedicated software component organizes the interplay of the different modules (see Figure 3). This allows a "loose coupling" between the modules, in that each module is a self-standing executable and interacts with the other modules through the integrated database (see Strauch et al. 2005).

4. The study area

The study area of ILUMASS consists of the metropolitan area of Dortmund in the Ruhr industrial district in Germany (see Figure 4). It comprises 26 municipalities with a population of 2.6 million. About 85 000 firms are located within the region. Although official sources in Dortmund assume a moderate population growth, the whole area is dominated by demographic and economic decline. This goes along with a profound change of the various economic structures: in the past, Dortmund was dominated by coal mining and steel manufacturing. The region is polycentric, with rural and semi-rural areas scattered between the urban centers.

The base scenario of ILUMASS assumes the most likely future development of the spatial and transport infrastructure in the study area based on current planning documents.

5. First results

At the beginning of the ILUMASS project, it was planned to simulate various policy scenarios in which the impact of different land use and transport policies were to be predicted until the year 2030. However, the project ultimately ran out of time, so it was only possible to do a few test scenarios.

Figure 5 demonstrates typical results of the simulations. Starting from land use, workplaces and population (aggregated for the transport model to a coarser grid of 1500 by 1500 m) the demand for transport is assigned to the network. The resulting traffic flows are used to compute emissions caused by traffic and air quality and traffic noise by grid cell.

A typical, aggregated result of the transport model is shown in Figure 6, which depicts the changes in the number of trips performed by different person groups between 2000–2005 and 2000–2010 (Mühlhans 2006). Although the total number of trips is increasing, the various groups demonstrate quite different change patterns. Note that the complete activity classification contains 29 different activities, here summarized into three main groups: school, work and other trips.

In order to be able to simulate a greater number of policy scenarios, a reduced version of the ILUMASS model was implemented in which, instead of the computing-time intensive microsimulation of travel demand, the aggregate transport model of the model of the Dortmund region developed at IRPUD was applied (Wegener 1998; Moeckel et al. 2006).

As an example for the simulated scenarios, the impact of a land use planning scenario on the spatial distribution of workplaces in the study region are presented in Figure 7 (Moeckel 2007). The scenario shows the response of the

Fig. 4: The study area: the Dortmund metropolitan area (Moeckel et al. 2004).

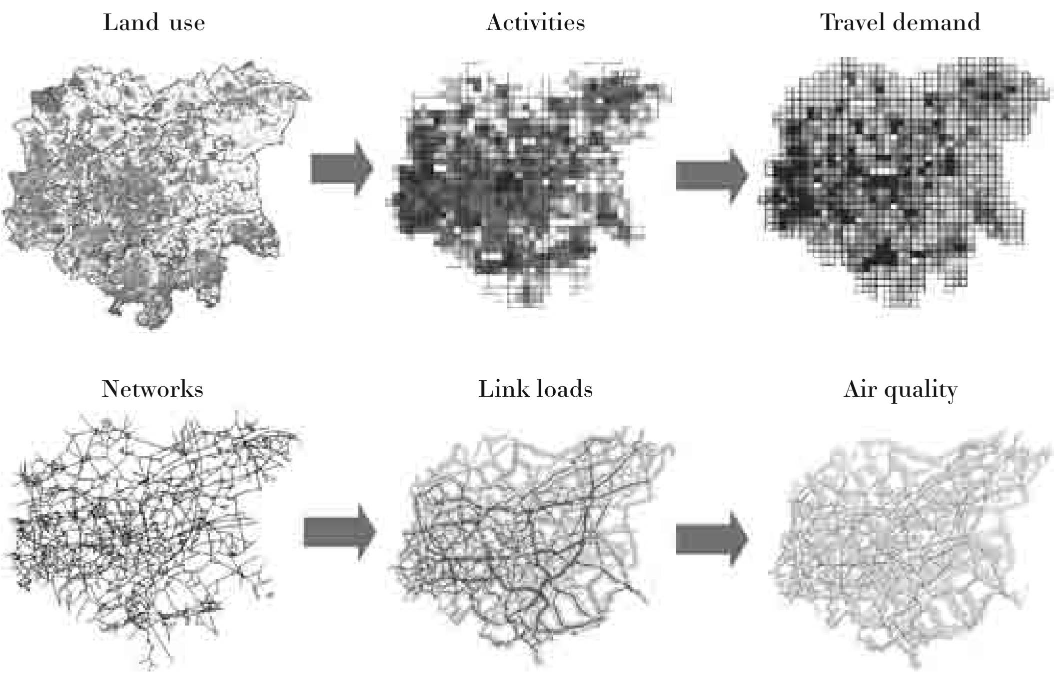

Fig. 5: Typical ILUMASS results.

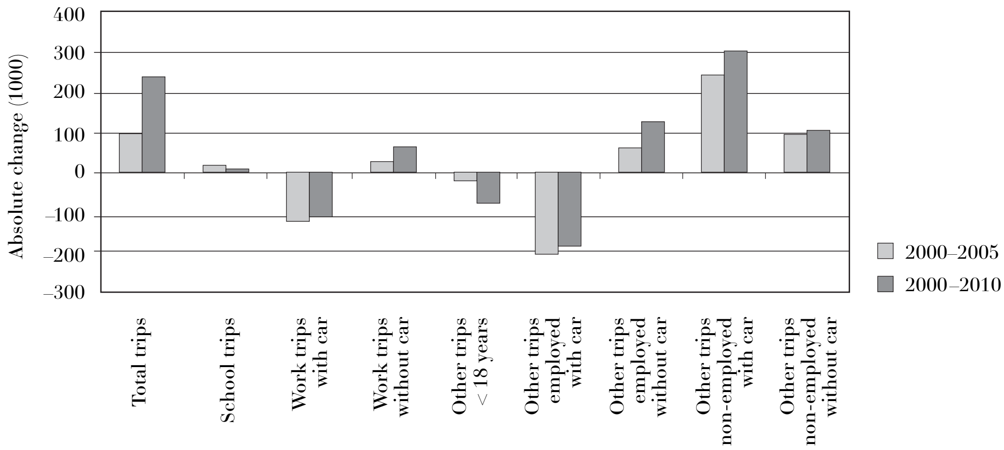

Fig. 6: Changes in the number of trips between 2000–2005 and 2000–2010 for selected activities.

location decisions of individual firms on the changes in land available for development (in the scenario). Figure 7 shows the changes in the distribution of workplaces as three-dimensional surfaces:

First, the base scenario of the expected development between 2000 and 2030 was run. In the base scenario, no planning policies working against current trends in land use development were implemented. Figure 7 (a) shows the change in the number of workplaces in the raster cells of the study area between 2000 and 2030: "the hills" (darker areas) indicate growth in workplaces and "the valleys" (lighter areas) indicate decline. It can be seen that the general trend of suburbanization of workplaces continues in the model. In particular, the city center of Dortmund loses jobs, but so do most of the other larger cities in the study area.

The land use scenario shown examines the effects of a strict anti-sprawl policy as an attempt to return to higher-density mixed-use urban forms (compact city). In the compact-city scenario, only the city of Dortmund is allowed to offer new land for commercial or industrial development; all other municipalities can only develop land that has already been designated. Figure 7 (b) shows the results of the compact-city scenario as the difference in workplaces between the policy scenario and the base scenario in the year 2030. "Hills" indicate that a raster cell has more workplaces in the compact-city scenario than in the base scenario in 2030; "valleys" indicate that it has less. During the 30 years simulated, Dortmund gains a significant number of workplaces at the expense of the other municipalities.

6. Critique

The ILUMASS project, although quite successful in terms of the progress made in the individual subprojects and from the perspective of bringing different disciplines together, has not met all of its initial goals. It was not possible to run more than a few test scenarios and the results from these scenarios have to be taken with some caution, because only very basic checks for plausibility and consistency could be made. This experience is not uncommon with large urban microsimulation projects in recent years. Many of these projects had to readjust their plans when the project targets proved to be too ambitious. This section analyses the specific reasons for the partial failure of the ILUMASS project. However, we are sure that most of the points elaborated below are not a special feature of ILUMASS, but are of a very general nature. Therefore, this discussion is presented in the hope of helping future large modeling projects surmount similar hurdles.

One fundamental reason for the partial success may be that scientists are often not very well prepared for the computer programming aspects (Wilson 2006a, b). However, there are other areas where the project was simply too inefficient in its work processes:

Application Programming Interfaces

There were serious difficulties in handling the application programming interfaces (API) needed to set up the simulation. Early in the project, the decision had already been made to connect the program modules developed at different research laboratories by "loose coupling",

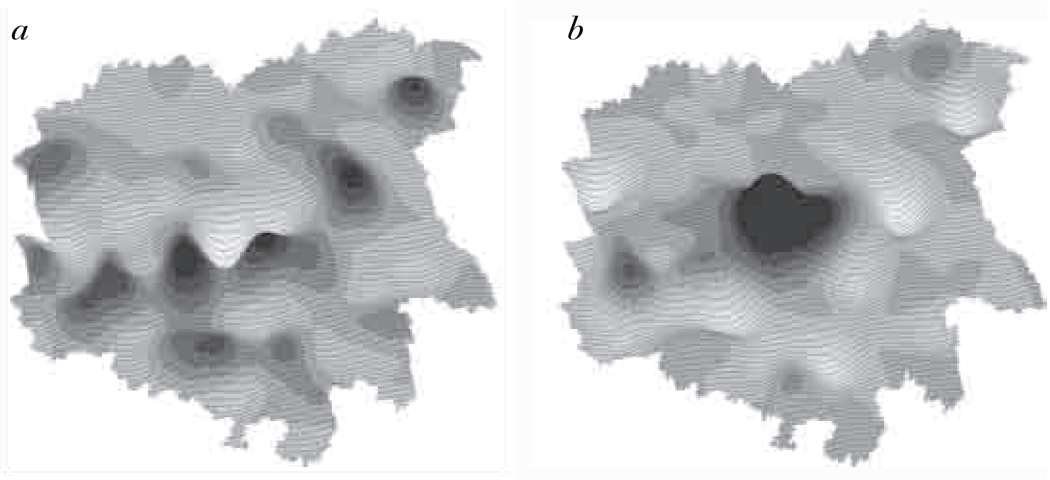

Fig. 7: Changes of workplace in the Dortmund urban region between 2000–2030 in the base scenario (a) and the differences between the base scenario and the compact-city scenario in the year 2030 (b) (Moeckel 2007).

i.e., to develop each of them as self-standing executables that communicate with the common database through application programming interfaces. Although the interfaces between the different modules had been structured very well, there were difficulties, not only in the conversion, but also in the quite protracted process of defining them. These definitions alone took more than one year, and consequently this time was missing in the end. Future projects should take care to have enough time planned for the definition of the APIs.

Testing

The testing process was clumsy and inefficient: While the API had been clearly defined, too many iterations were required to test their functionality until they finally worked together. One mistake was the focus of the project on a big solution, i.e., to immediately run the simulation for the whole area. The optimism that this should work was fuelled by the positive experiences within the group with several examples of successful large-scale cooperative programming projects. However, for this project, it was the wrong approach. It happened more than once that only at the end of a long simulation run, it was recognized that there was a slight error within one of the modules that rendered the whole simulation useless. And, even if the error had been detected, the process of correcting it was not fast enough.

It is apparent what should have been done here. First, the early testing processes mentioned above should have been implemented, and second, it would have been much better in the beginning to define small test cases where the whole model chain could have been run within seconds to find the more apparent errors. In this case, it would have even been possible that each group and each programmer could have run the whole model chain on his/her own computer to make sure that everything worked well.

Data exchange

The project team had too little experience in cooperative software development. The exchange of data between the different modules was far from optimal. It had been decided at the beginning of the project that the data exchange between the different modules should be file-based. Although a direct exchange via the main memory of the computer would have been preferable, since there were huge amounts of data to be exchanged, this would have required a much more direct and even more concurrent form of software development. In the ideal case, the various source codes should have been laid open at least within the consortium. This, however, had not been seen as an option, let alone the complexities of a much more coordinated software development process. Under these circumstances, a data exchange based on files seemed to be the best option, despite its clumsiness. Nevertheless, future projects should think about an open-source structure of such a project, with all its advantages and disadvantages.

Computing time

Computing time turned out to be a major problem. A large microscopic simulation is a time-consuming endeavor. Although such simulations are, in principle, capable of delivering more detailed results, the question of whether they are worth the additional resources is still not answered. What might be interesting in this discussion is that the most time-consuming parts in this simulation chain are, in this order, the calculation of travel demand, the calculation of shortest paths and the microscopic traffic flow simulation. All other parts, such as the land use submodels and the computation of emissions and air quality, do not take more than a few minutes of computer time – although environmental impact models using a higher spatial resolution also require a considerable amount of computing time. The travel demand and traffic assignment models, however, use from several hours to several weeks of computing time depending on the method used. This is too long to conduct enough tests or to run enough scenarios. In addition, long simulation runs require really efficient and stable computer platforms, which could not always be provided.

It is another question how the computations to be performed can be organized more efficiently. Despite all advances in computing technology it might be necessary to work with multi-level models which are microscopic where necessary and aggregate where an aggregate model is sufficient. However, it has not been demonstrated convincingly where the boundaries between "necessary" and "sufficient" actually lie. Therefore, one of the next tasks to be tackled is to understand how necessary and sufficient can be measured, and, equipped with such a measurement tool, to map out this area.

Cooperation

The cooperation between the project teams was difficult because of different disciplinary research traditions and scientific standards. This was particularly relevant where decisions had to be made about the appropriate level of detail and complexity of the model. Two different attitudes had to be reconciled: One view saw the empirical thoroughness as top priority, even when it became apparent that the resulting complexity would make the model too large to be operational. The other view put practical feasibility first, even at the expense of scientific rigor and validity. It would have been necessary to reach a consensus about the best solution to this conflict at an early stage of the project. It might have helped if the research groups would have had the opportunity to work together at one location for several weeks. This would have increased the financial demand of the project but would probably have paid off in the end in terms of the achievement of the project goals.

However, despite these difficulties, the project groups were highly motivated, concentrated and eager to bring the project to a successful end. Even one year after the financial resources had been exhausted, there was still a lot of project activity. So it might be said that the project was a fruitful cooperation. Right now, it is unlikely that the project will be continued in the near future.

7. Conclusions

The ILUMASS project can be regarded as a major step towards an integrated microsimulation model of urban land use, transport and environment. It has, however, demonstrated that there are still major hurdles to overcome.

A comprehensive evaluation of microsimulation models for urban, transport and environmental planning leads to a differentiated assessment of their advantages and disadvantages. There can be no doubt that microsimulation models are an important step forward in integrated land use and transport modeling. Only with microsimulation models is it possible to model societal developments, such as new life styles and work patterns and new tendencies in mobility behavior. Only with microsimulation models is it possible to forecast the impacts of innovative policies in the fields of travel demand management and transport operation. Only with microsimulation models is it possible to model the environmental impact of land use and transport policies with the necessary spatial resolution.

However, microsimulation models are not a universal solution. There are theoretical limits to increasing the spatial, temporal and substantive resolution of behavioral models when further disaggregation does not bring any additional information. There are empirical limits when the marginal costs of obtaining micro data are larger than their added value. There are practical limits when the computing time of the models exceeds the duration of the modeled processes. There are, finally, ethical limits to the collection of data about private lives for research.

The conclusion is that for every modeling problem, there is an optimum level of substantive, spatial and temporal resolution. This suggests that future urban models will be multi-level in substance, space and time. The challenge is to develop a theory of balanced multi-level models which are, to quote Albert Einstein: "As simple as possible – but no simpler."

Acknowledgements

The authors wish to thank their ILUMASS colleagues for the privilege of reporting on the common project work: Klaus J. Beckmann, Heike Mühlhans and Guido Rindsfüser of the Technical University of Aachen, Ulrike Brüggemann and Harald Schaub of the University of Bamberg, Rainer Schrader and Jürgen Gräfe of the University of Cologne, Rolf Möckel and Björn Schwarze of the University of Dortmund, Felix Huber and Hans Meiners of the University of Wuppertal and Peter Mieth, Michael Spahn and Dirk Strauch of the German Aerospace Center Berlin. Detailed information about their work is contained in the Final Report of ILUMASS (Beckmann et al. 2007).

In addition, we would like to thank all our colleagues for their enthusiastic cooperation in this demanding project. Financial support was provided by the German Federal Ministry of Science and Education and is gratefully acknowledged.

References

Arentze, T.; Timmermans, H. J. P. (2004): A Learning-Based Transportation-Oriented Simulation System. *Transportation Research Part B*, Vol. 38, 7: 613–633.

Arentze, T.; Timmermans, H. J. P. (2000): *ALBATROSS – A Learning-Based Transportation-Oriented Simulation System*. Eindhoven: European Institute for Retailing and Services Studies (EIRASS).

Beckmann, K.J.; Brüggemann, U.; Gräfe, J.; Huber, F.; Meiners, P.; Mieth, P.; Moeckel, R.; Mühlhans, H.; Rindsfüser, G.; Schaub, H.; Schrader, R.; Schürmann, C.; Schwarze, B.; Spiekermann, K.; Strauch, D.; Spahn, M.; Wagner, P.; Wegener, M. (2007): *ILUMASS Integrated Land use Modelling and Transportation System Simulation*, Endbericht (Final Report, in German).

Ettema, D.; Timmermans, H. (2006): Multi-agent modelling of urban systems: a progress report of PUMA System. *Stadt Region Land* 81. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, pp. 165–171.

Gawron, C. (1998): An Iterative Algorithm to Determine the Dynamic User Equilibrium in a Traffic Simulation Model, *International Journal of Modern Physics C*, Vol. 9, No. 3 (1998) pp. 393–407, doi: 10.1142/S0129183198000303.

Miller, E. J. (2001): *Integrated Land use, Transportation, Environment (ILUTE) Modelling Systems*, http://www.ilute.com/ (Access: 01.04.2005).

Miller, E. J. (2006): Integrated urban modelling: some theoretical considerations. *Stadt Region Land* 81. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, pp. 71–79.

Miller, E. J.; Hunt, H.D.; Abraham, J.E.; Salvini, P. A. (2004): Microsimulating urban systems. *Computers, Environment and Urban Systems,* 28: 9–44.

Moeckel, R. (2007): Business Location Decisions and Urban Sprawl: A Microsimulation of Business Relocation and Firmography. *Dortmunder Beiträge zur Raumplanung* 126. Dortmund: Institute of Spatial Planning, University of Dortmund.

Moeckel, R.; Schwarze, B.; Wegener, M. (2006): Das Projekt ILUMASS – Mikrosimulation der räumlichen, demografischen und wirtschaftlichen Entwicklung. *Stadt Region Land* 81. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, pp. 53–61.

Moeckel, R., Schwarze, B., Spiekermann, K., Wegener, M. (2004): Mikrosimulation verkehrsarmer Siedlungsstrukturen. *Stadt Region Land* 77. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, 187–206.

Moeckel, R.; Spiekermann, K.; Wegener, M. (2003): Creating a synthetic population. In*: Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management (CUPUM),* Sendai, Japan, Center for Northeast Asian Studies (CD-ROM).

Mühlhans, H. (2006): Das Projekt ILUMASS – Mikro-Simulation der Verkehrsnachfrage und des Verkehrsflusses. *Stadt Region Land* 81. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, pp. 33–51.

Mühlhans, H.; Strauch, D. (2005): ILUMASS – eine mikroskopische und dynamische Simulation des Systems Stadt. *Zeitschrift für Strassenverkehrstechnik* 5/2005.

Mühlhans, H.; Strauch, D. (2004): Mikroskopische Verkehrssimulation, Flächennutzung und Mobilität – Simulation der Dynamik des Systems Stadt. *Stadt Region Land* 77. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, pp. 173–186.

Mühlhans, H.; Rindsfüser, G.; Beckmann, K. J. (2004): Mikroskopische Simulation der Verkehrsnachfrage im Rahmen der integrierten Flächennutzungs- und Verkehrssimulation ILUMASS, *Stadt Region Land* 76. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, S. 113–130.

Schwarze, B.; Strauch, D.; Mühlhans, H.; Rindsfüser, G. (2004): Bedarf, Anforderungen und Verwendung räumlicher Daten in einer integrierten, dynamisch-mikroskopischen Sim-ulation der Stadtentwicklung, In: Raubal, M.; Sliwinski, A.; Kuhn, W. (eds.): *Geoinformation und Mobilität – von der Forschung zur praktischen Anwendung.* IfGI Prints 22. Münster: Institut für Geoinformatik, Universität Münster, S. 1–13.

Spiekermann, K.; Wegener, M. (2007): Environmental feedback in urban models. To be published in *International Journal of Sustainable Transport.*Strauch, D.; Moeckel, R.; Wegener, M.; Gräfe, J.; Mühlhans, H.; Rindsfüser, G.; Beckmann, K. J. (2005): Linking transport and land use planning. In: Atkinson, P.; Foody, G.; Darby, S.; Wu, F. (eds.): *GeoDynamics*. Boca Raton: CRC Press, pp. 295–311.

Wegener, M. (1998): *The IRPUD Model: Overview*. http://www.raumplanung.uni-dortmund.de/irpud/pro/mod/mod_e.htm (Access 26.11.2006).

Wegener, M. (2004): Overview of land use transport models. in: Hensher, D.; Button, K.J.; Haynes, K.E.; Stopher, P.R. (eds.): *Handbook in Transport*, Vol. 5. *Transport, Geography and Spatial Systems*. Oxford: Pergamon/Elsevier, pp. 127–146.

Weidner, T.; Donnelly, R.; Freedman, J.; Abraham, J.E.; Hunt, J.D. (2006): TLUMIP – transport land use model in Portland – current state. *Stadt Region Land* 81. Aachen: Institut für Stadtbauwesen und Stadtverkehr, RWTH Aachen, pp. 91–102.

Wilson, G.V. (2006a): Where's the real bottleneck in scientific computing? *American Scientist*: 94: 1, 5. (http://www.americanscientist.org/template/AssetDetail/assetid/48548).

Wilson, G.V. (2006b): *Software Carpentry*. http://www.swc.scipy.org/

Peter Wagner
Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
Institut für Verkehrsführung und Fahrzeugsteuerung
Rutherfordstr. 2
DE-12489 Berlin
peter.wagner@dlr.de

Michael Wegener
Spiekermann & Wegener
Stadt- und Regionalforschung
Lindemannstrasse 10
DE-44137 Dortmund
mw@spiekermann-wegener.de