MICROSIMULATION FOR INTEGRATED URBAN MODELLING

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Abstract: To test alternative land use and transport policies an integrated land-use transport environment model (LTE model) has been developed and applied to the Dortmund region in Germany. Whereas the transport module is aggregate, the land use and environmental modules are entirely microscopic. This paper shortly describes each module and reflects on advantages and drawbacks of microsimulation for urban modelling.

Keywords: Integrated modelling, microsimulation, micro data, land use, transport, environment

1. INTRODUCTION

Increased global warming and local environmental degradation demand that urban and regional politics reduce the environmental impacts of our daily activities. At the same time, competition among cities and regions for citizens and employment calls for an attractive and efficient land use and transport infrastructure system. The implementation of infrastructure usually is costly and irreversible; and policies restricting usage or imposing costs may be dolorous for certain user groups. Consequently, before implementing policies or building infrastructure, the efficiency and effectiveness need to be analysed carefully. For this reason cities aiming at sustainable development seek to understand and predict the likely impacts of planning policies. In addition to local knowledge, planning experience and public participation, mathematical simulation models support these decision processes in urban planning. Due to a strong interdependence of land use, transport, and the environment, integrated urban modelling allows to simulate the behavioural interactions of households, developers, businesses, transport and the environment.

This paper outlines the work on microsimulation of urban development performed at the University of Dortmund. First an introduction into microsimulation is given. Then the paper describes a microsimulation land use model that is combined with a microscopic environmental module and an aggregate transport model. This model has been implemented and tested in the Dortmund region in western Germany and is used to test land use, transport and fiscal policies. Some simulation results are presented and a critical reflection on the advantages of microsimulation is given.

2. MICROSIMULATION

In 1960 G. H. Orcutt and colleagues introduced microsimulation for modelling the behaviour of individual consumers in the U.S. economy (Orcutt et al. 1961, Orcutt 1960). In the following decades only few projects introduced microsimulation for urban modelling due to limited computational power and lack of appropriate theory.

A famous early example explaining the advantages of microsimulation was developed by T. Hägerstrand (1967). He studied the distribution of tuberculosis (TB) control in agriculture in a rural Swedish region. His model of spatial diffusion shows that farms that are located close to other farms that apply TB control are more likely to adapt this control. Every farm that "received" the innovation TB control becomes a "sender" itself, spreading this innovation to other nearby farms. Thus, microsimulation allows representing spatial diffusion. Another prominent example is the self-forming neighbourhood model developed by T. A. Schelling (1978). In this model individuals of two distinguishable groups, such as rich and poor, black and white, or students and professors, select a location on a checkerboard. Each individual accepts a certain number of individuals of the other group. If the number of neighbours of the other group is too high, the individual will decide to relocate. After several iterations an equilibrium is reached, every individual has no more neighbours of the other group than it was willing to accept. Due to a microscopic chain reaction leading individuals that are unsatisfied with their neighbourhood towards clusters of one's own kind, the resulting segregation is much higher than the individual claim.

Recently, land-use transport models are extended by modules simulating the impact of land use and transport on the environment. More advanced models even represent the environmental feedback from the environment on land use by modelling, for instance, households moving to dwellings further away from noisy streets and closer to greenfield areas. The scale of aggregate models is too coarse to represent the selection of micro locations (Spiekermann and Wegener 2000). In contrast, microsimulation allows to simulate the quality of locations at a much finer level. For instance, a dwelling with a noisy street side may offer a quiet garden in the backyard.

The examples of spatial diffusion, self-forming neighbourhoods or environmental feedback prove that there are phenomena that cannot be simulated at the aggregate level but require a microscopic reproduction of individual behaviour. With the growing availability of faster personal computers, microsimulation has become more feasible for urban modelling (Timmermans 2003, Wegener 2004). Today, the bandwidth of possible microsimulation applications include many different topics, such as models to simulate urban development, housing markets, transport behaviour, demographic change, innovation diffusion or health care planning (Clarke and Holm 1987).

Worldwide, several teams work on the development of integrated models simulating land-use and transport, sometimes even including the environment (Wegener 2004). Recently, several approaches moved from aggregate modelling techniques to microsimulation. The most prominent examples include the ALBATROSS model developed at several Dutch universities (Arentze and Timmermans 2000), the California Urban Futures model (CUF) developed at the University of California at Berkeley (Landis and Zhang 1998a, 1998b), the ILUTE model developed at Canadian universities (Miller et al. 2004, Salvini and Miller 2003, Miller and Salvini 2001), the PUMA model at Utrecht University in the Netherlands (Ettema and Timmermans 2006, Ettema et al. 2004), SIMDELTA of David Simmonds Consultancy in Cambridge, England (Simmonds and Feldman 2005), TLUMIP for the U.S. State of Oregon (Weidner et al. 2006) and UrbanSim developed at the University of Washington in Seattle (Waddell et al. 2003, Waddell 2002, 2000). All of them have the common paradigm that microsimulation improves the reliability and accuracy of urban simulation models. So far, only few examples have been able to prove this hypothesis.

3. MODEL OVERVIEW

The model is based on work accomplished in the ILUMASS (Integrated Land Use Modelling And Transportation System Simulation) project (Strauch et al. 2005). This project was a joint research effort of institutes at the German Universities of Aachen, Bamberg, Cologne, Dortmund and Wuppertal led by the Transport Research Institute of the German Aerospace Centre (DLR) and funded by the German Federal Ministry of Education and Research (BMBF). The consortium developed an integrated model that works entirely microscopic, including land use changes, activity generation, trip assignment and environmental impacts. The Institute of Spatial Planning at the University of Dortmund in cooperation with Spiekermann & Wegener, Urban and Regional Research was responsible to design and implement the synthetic micro data and the land use simulation. While developing improvements for the land use modules, the complex transport simulation was replaced by a fast-running aggregate transport model for test purposes, and the environmental module will be replaced by a different model estimating environmental impacts. This gave the authors the opportunity to execute hundreds of test runs to further develop and calibrate the land use model. This paper presents this simpler model version with the aggregate transport model.

The applied approach is outlined in Figure 1. The boxes with a dotted line show the microscopic input data. For privacy reasons, real micro data are not available in Germany. Thus, synthetic micro data were generated using available aggregate data sources. These synthetically generated micro data cover households and persons, firms and workers, dwellings and non-residential floorspace. Additionally, the road network, the public transport network, and the existing land use pattern were digitised for the study area. The largest box shown in yellow outlines the land use model. On the upper left side the module Demography updates households and persons through demographic events such as aging, birth or death. Below the module Moves of households simulates the relocation of households and housing search by newly established households. The module Update of dwellings represents the developers who build, modernise or demolish dwellings. Both, moves of households and construction of dwellings are strongly influenced by the attractiveness of zones, which includes attributes of the zones themselves, environmental indicators and accessibility indicators describing their location within the urban area.

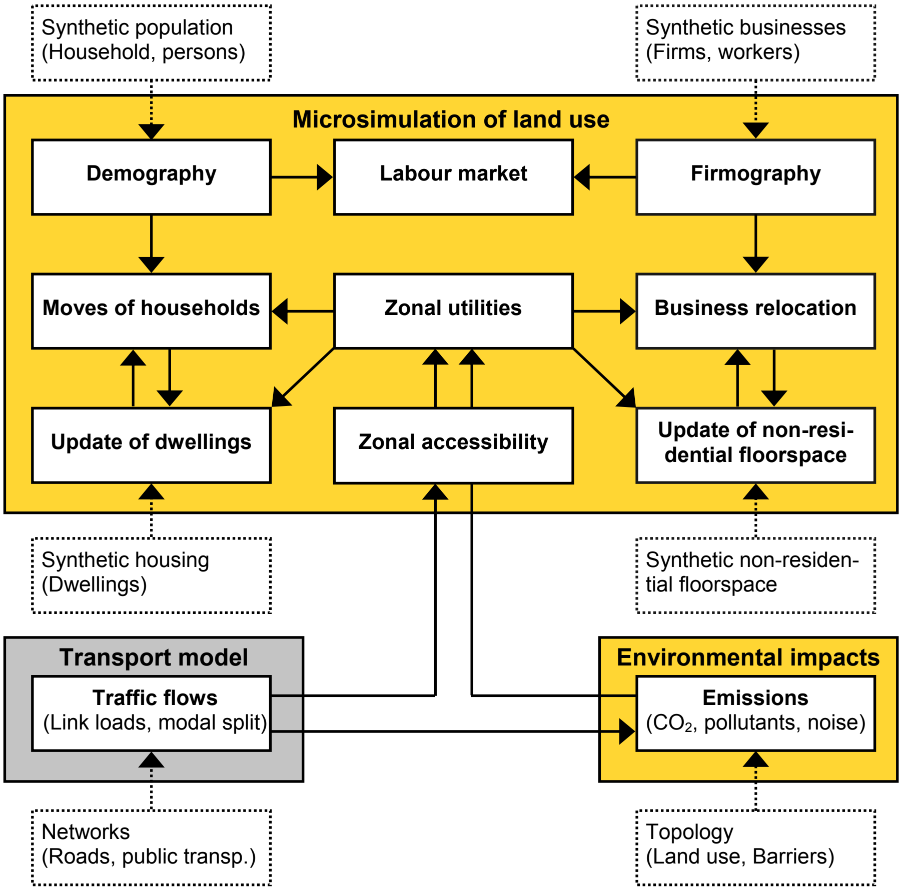

Figure 1: Model overview

On the upper right side of the land use model the Firmography module simulates the demography of firms by events such as birth, growth, decline or closure. The Labour market links persons and firms by job search, job change or layoff. Whereas the Business relocation module finds new locations for firms, the Update of non-residential floorspace represents the behaviour of developers. Just as for households, both modules strongly depend on the attractiveness of zones. The transport model shown in grey simulates trips and modal split within and between zones. The estimated travel costs and travel times are used to calculate zonal accessibilities to various destinations, such as jobs, schools, or retail facilities. The module Environmental impacts calculates the effects produced by traffic flows and network infrastructure. This microscopic module estimates, among others, gaseous emissions and noise. The information is fed back into the land use model and influences future location choices.

4. STUDY AREA

The model is applied to the urban region of Dortmund in western Germany. The left part of Figure 2 shows the study area used by the land use and the environment model. The area covers the city of Dortmund in the centre and 25 surrounding municipalities. The region is subdivided into 246 zones and has a population of 2.6 million and roughly 1 million jobs. For the simulation of environmental feedback or local interactions of individuals zones are too coarse (Spiekermann and Wegener 2000). For this reason, the study area has been subdivided into raster cells of 100 by 100 metres width. The study area has approximately 207,000 such raster cells. The right part of Figure 2

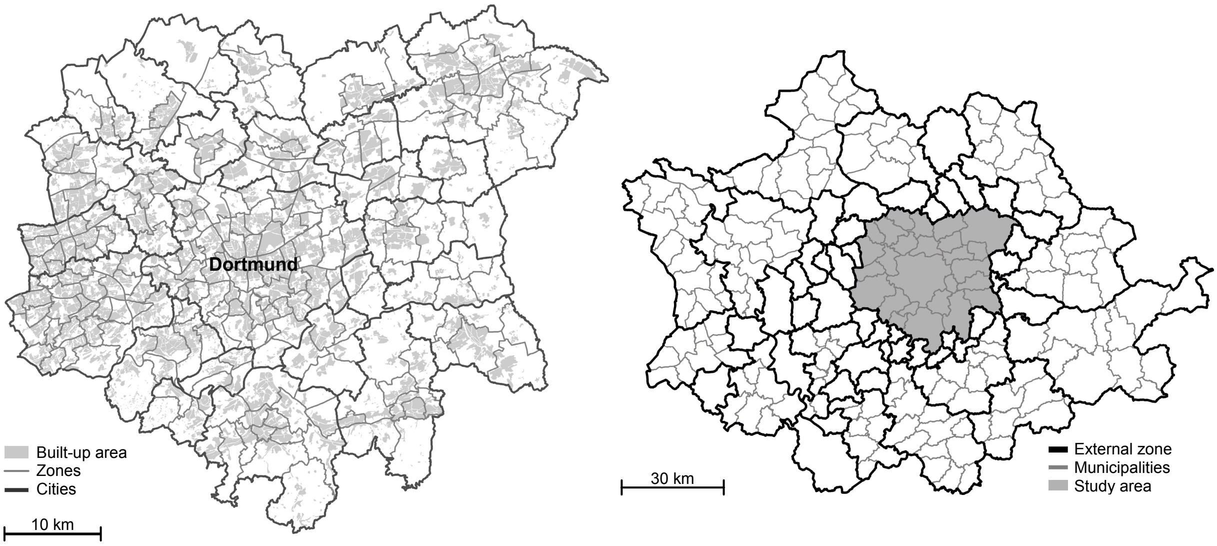

Figure 2: The Dortmund study area for land use (left) and transport (right) simulation

shows the extended study area of the transport model for which 54 external zones were added to simulate trips beyond the border of the study area.

5. SIMULATION MODULES

The simulation model consists of eight modules that are closely linked in one executable programme file. The entire model is written in Fortran and runs over 30 simulated years in approximately one and a half hour on a high-level PC.

5.1 Synthetic micro data

Microsimulation models require micro data with detailed information about single actors. For persons, for example, socio-demographic characteristics such as age, gender, income or education, are necessary to simulate their behaviour in terms of land use and transport. Commonly, due to privacy reasons these micro data are not available. Instead, only aggregate data are published. For simulation purposes, it is sufficient to generate synthetic micro data from available aggregate data. These micro data do not describe real persons but persons that are similar to those found in the real world. The totals of the synthetically generated micro data equal the available aggregate real data.

To generate the synthetic micro data, two methods were applied. Iterative Proportional Fitting was used to generate multi-dimensional data from available one-dimensional data. For instance, data on households by size and households by income were merged into a two-dimensional table of households by size and income. The second method is Monte-Carlo Sampling. This procedure applies probabilities calculated by Iterative Proportional Fitting and selects different attributes one by one until the micro data have the required detail. For households, for instance, size or housing location were selected by Monte-Carlo Sampling.

5.2 Demography

The synthetically generated micro data need to be updated every year. For persons the simulated events include aging, marriage/cohabitation, birth of children, divorce/separation, children leaving the parental household, starting shared housing, death, start/change/end education and employment and adjustment of income. In every simulated year every person is selected, and demographic changes are simulated based on the person's characteristics. This does not include housing choice, as the residential location is assumed to be a household decision that is modelled in a separate module described in Section 5.3.

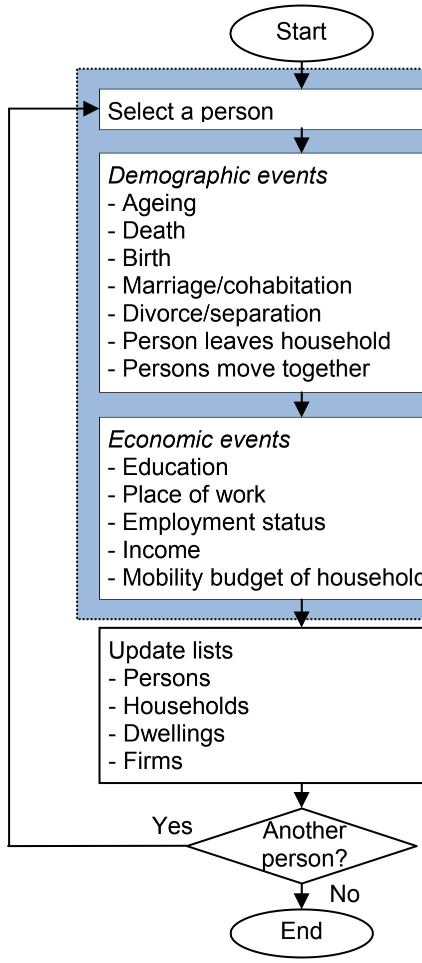

Figure 3: Simulation of demography

Figure 3 presents the module that simulates demography. A person is selected and demographic events are simulated first. Next economic events are modelled. For efficiency reasons every list entry is updated "on the fly", i.e. if someone retires the employment status is changed in the list of persons and the person is removed as an employee at its workplace in the list of firms.

5.3 Moves of households

The *residential mobility* submodel models location and housing decisions of households who move into the region (immigration), move out of the region (outmigration), move into a dwelling for the first time (starter households), or have a dwelling and move into another dwelling (moves). The submodel is based on a similar submodel of the IRPUD model, which was designed as a microsimulation model already before ILUMASS (Wegener, 1986).

Moves are modelled as Monte Carlo simulation of transaction of households and landlords on the regional housing market. A market transaction is every successful operation by which a household moves into or out of a dwelling or both. The attractiveness of a dwelling for a household is a weighted aggregate of the attractiveness of its location, its quality and its rent or price in relation to the household's housing budget.

A move can be effected in two ways: a household looks for a dwelling (housing demand) or a landlord looks for a tenant or buyer (housing supply). In the first case the household first selects a zone and then a vacant dwelling in the zone. If the offered dwelling promises a significant improvement of its housing satisfaction compared to its 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. In the second case the landlord looks for a household, if necessary in several attempts. Figure 4 shows the steps of the two search processes.

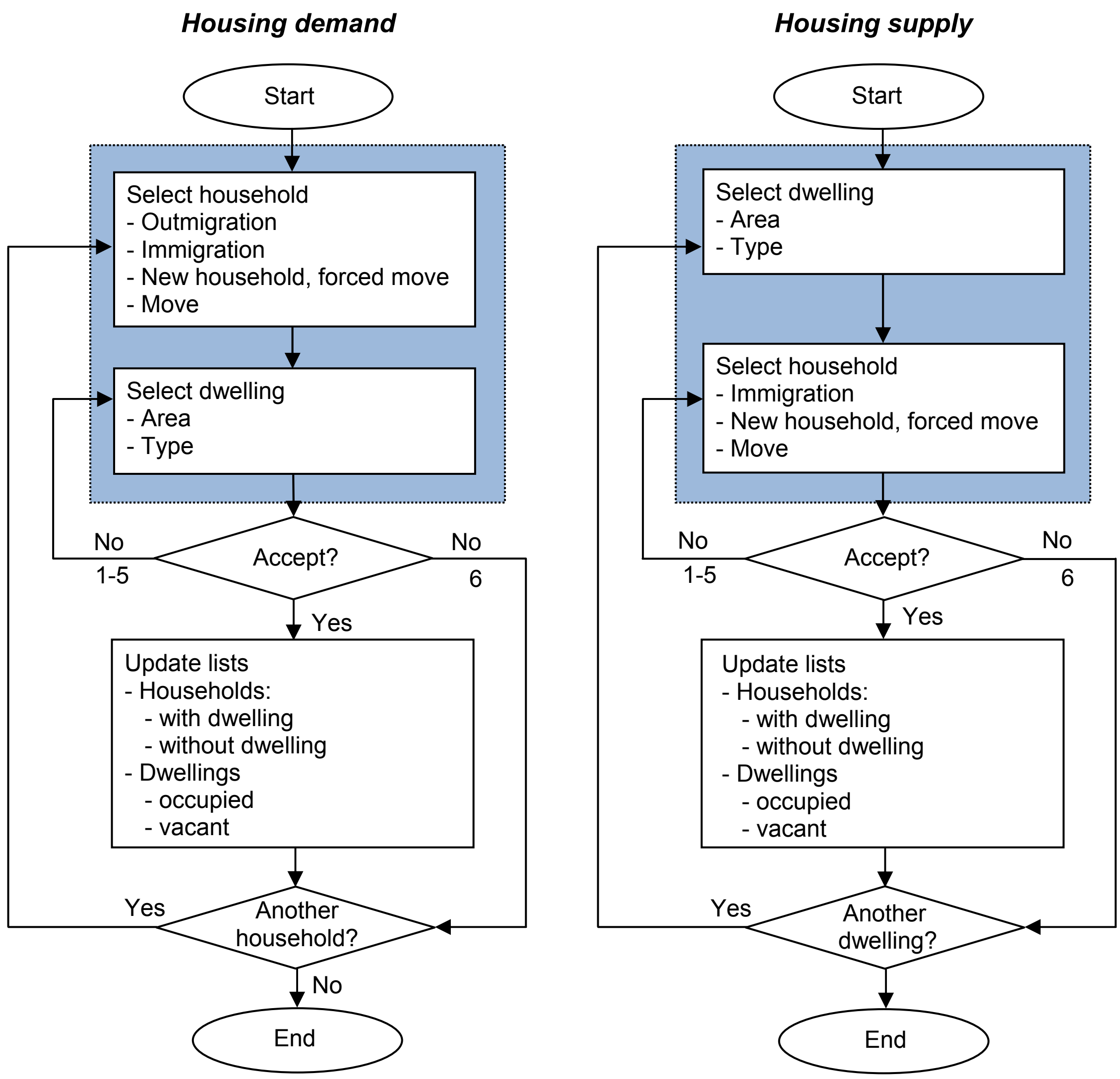

Figure 4: Microsimulation of residential mobility

5.4 Update of Dwellings

The *developers submodel* simulates investment and location decisions on the real estate market by private developers. New houses and dwellings are constructed, and existing houses and dwellings may deteriorate, be upgraded, or be demolished. Decision processes are modelled hierarchically with logit models (Domencich and McFadden 1975) as a Monte Carlo simulation of investment and location decisions. Developers are assumed to invest in their housing stock if by doing so they can expect to raise their profits. Their investment decisions depend on the given supply and demand at a special submarket, the vacancy rates and their expected profits. Figure 5 shows the different stages of these modelling processes. For the construction of dwellings a new attractive and feasible location will be chosen that the land use planning had designated for residential development. While selected land is immediately covered by new buildings, new dwellings are not available until construction period has finished. At the end housing prices and rents are adjusted to reflect the changes in housing supply.

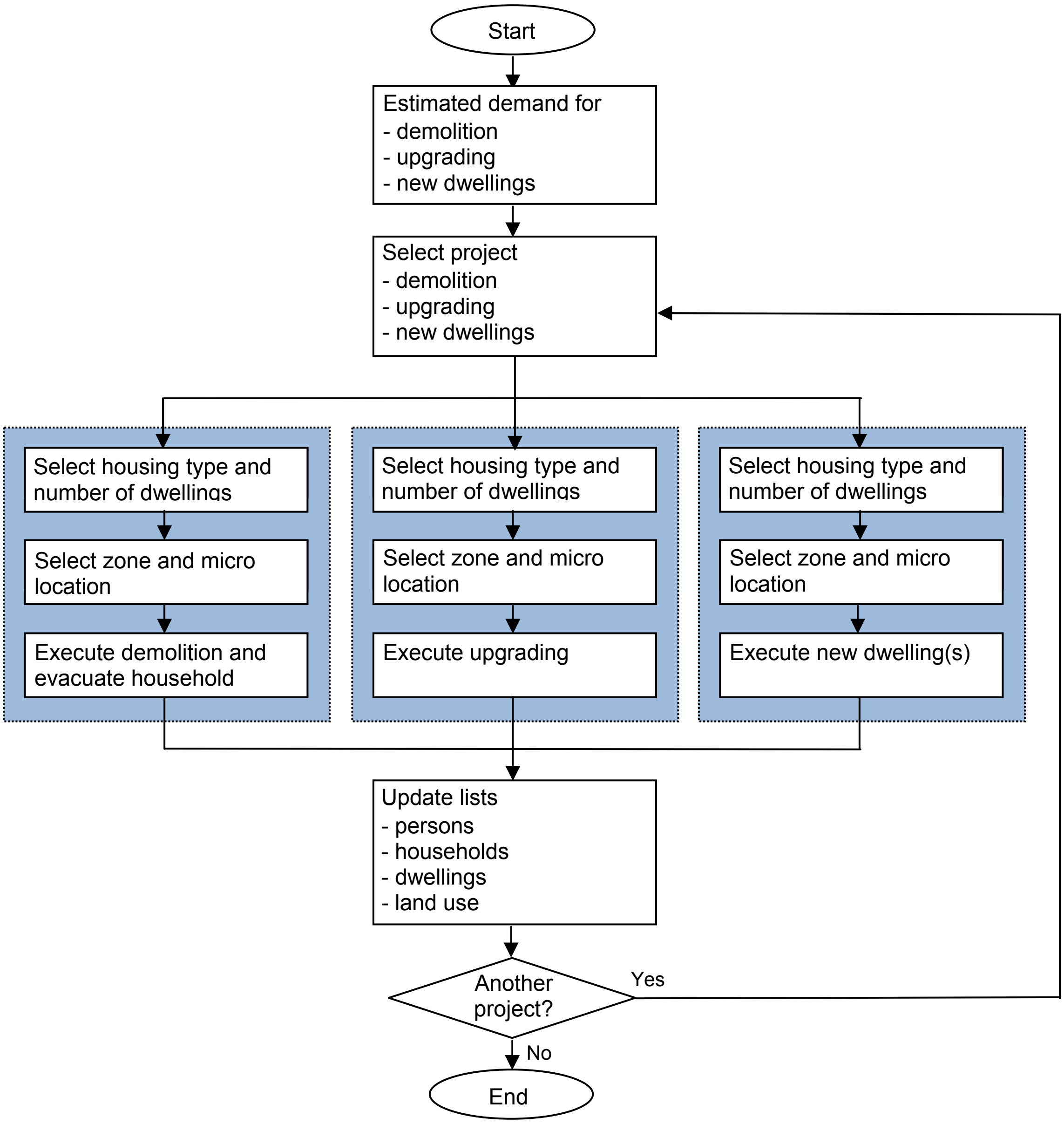

Figure 5: Microsimulation of developers

5.5 Firmography

Just like the population firms need to be updated by *Firmographic events* every simulation period. New businesses are established, some firms grow or decline and others are closed entirely. As these changes address the demography of firms this process also is called firmography. This module simulates all non-spatial changes; location search is described in section 5.6 by the module business location. Firmographic events are simulated by Markov models because the reasoning behind single firmographic decision is not of further interest in this context.

Employment change is driven by two aspects, namely economic restructuring and economic cycles. Economic restructuring describes the general trend of declining and growing business types. The model reflects this exogenously given trend by adjusting the number of business birth and closure accordingly. Economic cycles with upswings and recession phases, in contrast, influence all business types in the same direction, though some are more responsive to economic cycles than others. Economic cycles have influence on both growth/decline of firms and on birth/closure rates.

In general, only firms with 100 workers or less are considered to be closed. Equally, the size of newly established firms is limited to 100 workers. This limit is set to prevent simulating historic events in a stochastic process. If very large firms were born or closed randomly, the single event would overshadow the effects of policies tested in different scenarios. If desired, birth and closure of very large firms can be set exogenously to be executed identically in every scenario. The actual size of a firm to be born or closed is calculated by an exponential function giving a high probability to smaller firms and a small probability to larger firms. This is based on empirical evidence that large firms are rarely closed all at once. They rather attempt to overcome economic difficulties by reducing workforce than by closing the entire firm.

Growth and decline are simulated influenced by economic restructuring and economic cycles. The targeted employment change is used to set growth and decline probabilities as shown in Figure 6. The grey line represents the normal distribution of growth and decline probabilities if the targeted change is 0 percent. Most firms will not change at all, but a few will grow and a few will decline, resulting in the overall change of 0 percent. If the targeted change is +8 percent (red line) the normal distribution is shifted to the right. In this case the majority of firms will grow, but some might decline even though the overall situation is favourable for this business type. In recession phases the curve is shifted to the left as shown by the blue line.

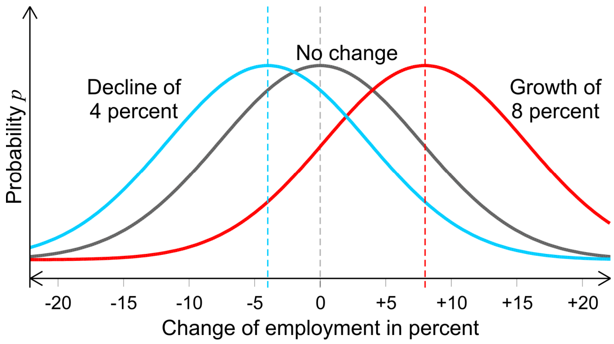

Fig. 6: Probability for growth and decline

5.6 Business relocation

New businesses that have been established need to find a location. Existing businesses may search for a new location if their current location conditions are unsatisfying. These decisions are simulated by logit models.

Every simulation period the satisfaction of each business with its current location is analysed. The relevant location factors include aspects such as rent, accessibility of customers, closeness to competitors, image or available floorspace. Since businesses tend to move over small distances only (Birch 1984) closeness to the previous location is another important location factor. According to a study of German manufacturing, firms divide location aspects in limitational, i.e. non-replaceable, and substitutional, i.e. replaceable, location factors (Lüder and Küpper 1983). Therefore, location factors are divided into essential and desirable ones, or non-replaceable and replaceable ones. Whereas all non-replaceable location factors have to be fulfilled to a certain degree, replaceable location factors may substitute each other. This distinction is achieved mathematically by aggregating non-replaceable location factors by a Cobb-Douglas-Function and replaceable location factors by simple weighted addition.

Firms that are unsatisfied with the current location because the site is too small receive the option to rent adjacent additional floorspace or to establish a branch. If the business prefers to relocate entirely or if the business is newly established a new location is searched in two steps. First a zone is chosen by a multinomial logit model. Then, a micro location within the selected statistical zone is chosen by another multinomial logit model. Larger firms need to find a site located on several adjacent raster cells.

After an alternative micro location has been selected the attractiveness, or utility, of that location for the business is evaluated. Most businesses search a few sites before taking a relocation decision. The number of sites searched is simulated dynamically, i.e. the number depends on the quality of the found alternatives. Up to ten different locations are searched. Then, the firm has the option to decide if it wants to move at all given the found alternatives, which is simulated by a binomial logit model.

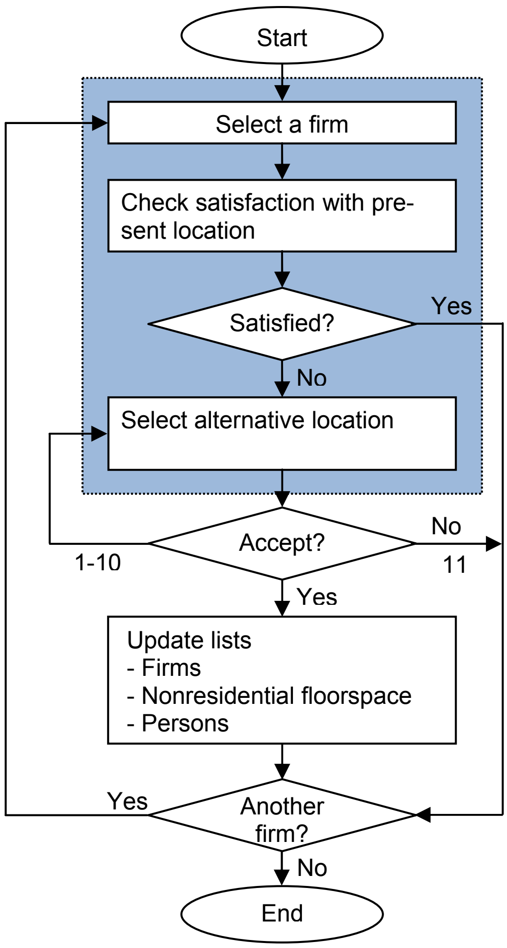

Figure 7: Microsimulation of business relocation

5.7 Environmental impacts

The *environmental impact model* calculates different environmental indicators based on the output of the transport and land use models. The model consists of five submodels:

(1) The *emission* submodel uses a very detailed and dynamic classification of the vehicle fleet and speed-related emission functions to calculate CO_2 and air pollutant emissions from modal traffic flows.

(2) The *air pollution and exposure* submodel applies a Gaussian air dispersion model to the emissions to calculate air quality at the places of residence of the population.

(3) The *noise* submodel calculates noise generation at sources and noise propagation to residential locations.

(4) The *environmental quality* submodel calculates a land fragmentation index as contiguous open space undisturbed by traffic noise.

(5) The *accessibility to open space* submodel calculates a potential indicator in which the attraction term is open space and the impedance is walking distance.

The environmental indicators will be fed back into the land use model to form part of the location decision of households and firms.

The model is currently working as an add-on module (Spiekermann, 2003), i.e. it is not fully integrated in the modelling system and the environmental feedback to the land use model is still under development.

5.8 Transport

The *transport submodel* provides travel time and travel cost data for the calculation of accessibility indicators for the residential and non-residential development and household and firm location submodels. It calculates work, shopping, service and education trips for four socio-economic groups and three modes: car/motorcycle, public transport and walking/cycling. The model determines a user-optimum set of flows where car ownership, trip rates, modal split and route choice are in equilibrium subject to congestion in the network. The transport submodel proceeds in five steps:

(1) In the *trip generation* step, trip origins and destinations are calculated as a function of origin and destination activities.

(2) The *car-ownership* model estimates the number of cars owned in each zone by each socio-economic group as a function of household travel budgets and expected travel expenses.

(3) In the *network analysis* step for each mode and pair of zones the shortest route through the appropriate network is determined. In the public transport network, transfers between lines are automatically effected taking account of access and waiting times.

(4) In the combined *trip distribution and modal split* step traffic flows between zones by mode and purpose are estimated as a function of origins and destinations and trip utilities. The trip distribution model is doubly constrained for work and school trips, but singly constrained for shopping and service trips. Modal shares are calculated

for each origin-destination relation and each household travel budget group based on the comparison of trip utilities. The model assumes that all available cars may potentially be used for work trips and that there are captive users for either public transport or walking.

(5) In the *trip assignment* step trips are loaded on the links of the shortest routes determined for each mode. Link travel times of congested road links are adjusted using a speed-flow relationship.

Network capacity-flow equilibrium is approached by executing steps (1) to (5) several times and at each iteration adjusting trip rates, car ownership, travel flows and link loads following a generalisation of the algorithm by Evans (1976). Figure 8 is a flow diagram of the submodel.

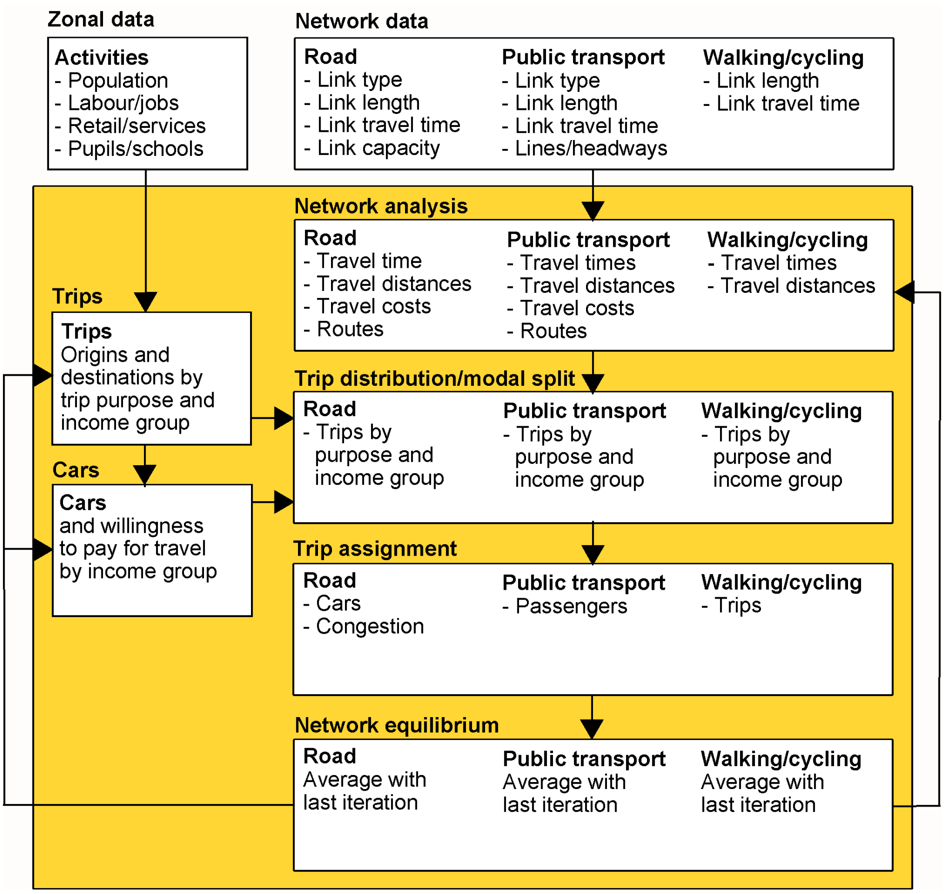

Figure 8: Transport model

6. SIMULATION RESULTS

The presented model has been fully implemented and tested. As much attention has been paid to efficient run times, it is possible to run the model several times per day to improve the performance and validity. The model simulates the years 2000 to 2030, a time span assumed to be large enough to show the effects of mayor transport and land use policies, and short enough to limit uncertainty. To provide one example of simulation results, the distribution of jobs in different scenarios based on Moeckel (2006) is presented. Even though single firm establishments are simulated in the model, the results are discussed in the form of distributions of jobs. As firm size varies, number of firms would not be meaningful for analysing urban planning policies.

Figure 9 (a) shows the change of total employment in the study area after 30 years. The model stores employment on the raster cells. To visualise urban patterns, a kernel estimation (Bailey and Gatrell 1995) was applied to interpolate raster cell data. In Figure 9 (a) blue areas are those that lost employment, whereas red areas gained employment within the simulated 30 years. A deep blue valley can be found in the centre of the study area, which is the centre of Dortmund. This area does not necessarily lose employment because it is unattractive, but rather because the average amount of floorspace used per employee is growing over time. As almost no new floorspace can be built in the centre, where no developable land is left, employment density of the city centre declines over time. The two adjacent red hills southeast and southwest of the Dortmund city centre are subcentres that gain significantly. Several suburban locations further to the east and to the southeast gain, too. The total study

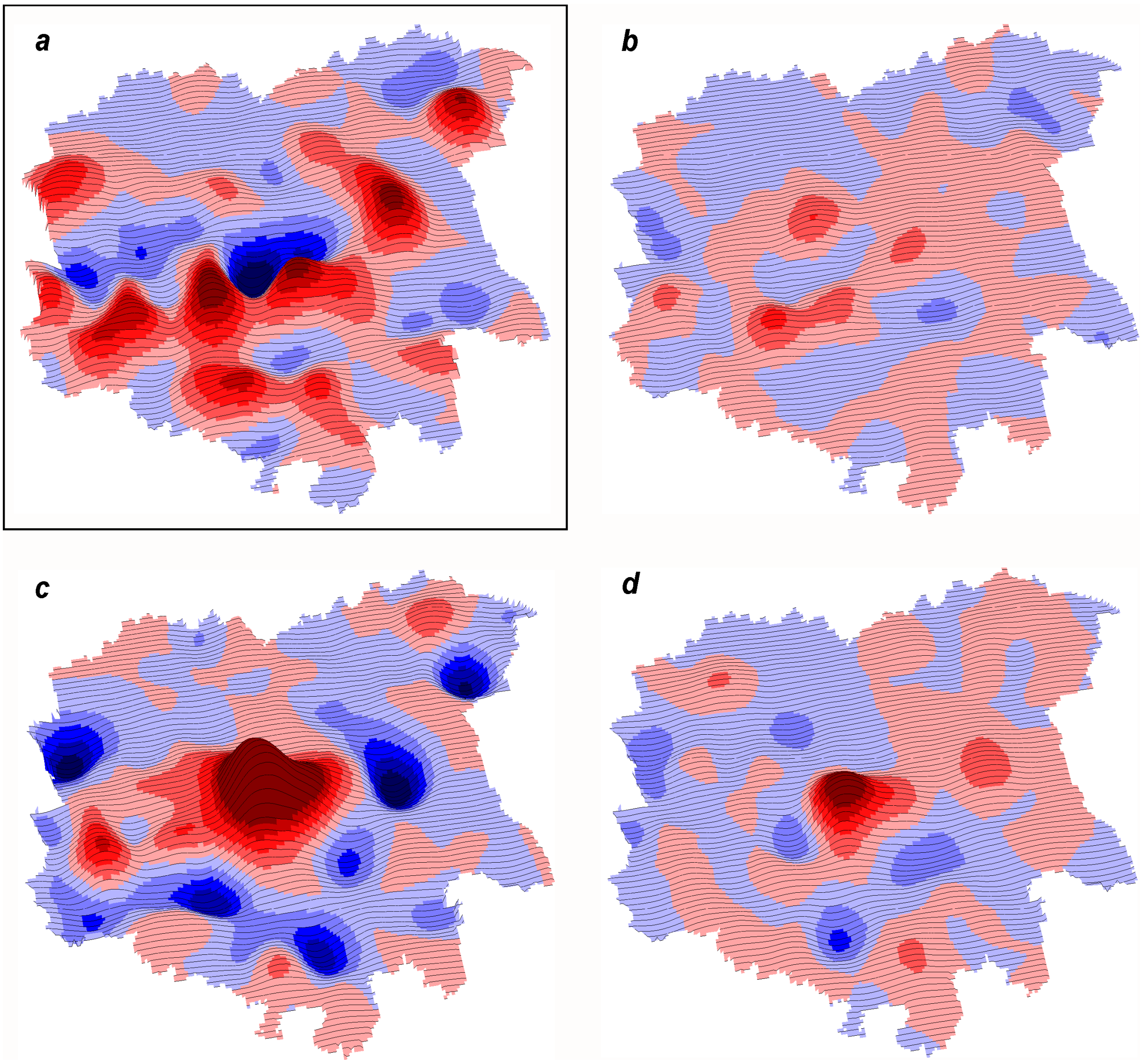

Figure 9: (a) Change of jobs in the Base Scenario between 2000 and 2030, (b) to (d) difference between Base Scenario in the year 2030 and (b) the Subsidy Scenario, (c) the Compact City Scenario, and (d) the Regional Cooperation Scenario.

area gains 3.0 percent employment over 30 years in accordance to exogenously given regional control totals. Whereas Dortmund gains 0.6 percent only, suburban towns gain 4.5 percent on average. The simulation indicates that the trend of suburbanisation of jobs observed in the past will continue in the future.

Figure 9 (b) shows the result of a Subsidy Scenario. In this scenario business taxes in Dortmund are reduced to the lowest value that is legal under German jurisdiction. All other cities keep the business tax rates that are applied in the Base Scenario. The picture shows the difference between the Subsidy Scenario and the Base Scenario, i.e. blue areas develop worse than the Base Scenario and red areas gain more employment than in the Base Scenario. The net effect of this scenario is small. Dortmund gains only 2.0 percentage points more employment. The estimated costs, however, would be approximately 53 million Euros per year (including additional business taxes received by employment growth in Dortmund), an unaffordable sum for a city like Dortmund that has struggled with a financial crisis for years.

The third scenario presented in Figure 9 (c) shows the difference between the Compact City Scenario and the Base Scenario. In this scenario, every new development of non-residential floorspace outside of Dortmund is prohibited. This limits the competition for Dortmund, and the city gains 9.7 percent points more than in the Base Scenario. However, this scenario appears unfeasible as surrounding cities are unlikely to stop floorspace development voluntarily. A more reasonable scenario is the Regional Cooperation Scenario shown in Figure 9 (d). In this scenario, the floorspace demand of the total area is assigned to every municipality based on their present number of jobs, i.e. larger cities are allowed to dedicate more land to non-residential floorspace development, whereas smaller suburban cities may add less floorspace. This scenario leads to the most balanced employment development. Dortmund gains 1.9 percentage points more than in the Base Scenario, whereas the suburban areas receive the same or a slightly smaller employment growth.

The results of these and further scenarios indicate that restrictions on land use development and transport reduce urban sprawl, road congestion and environmental emissions. Offering more sustainable options (pull measures) are less effective than restricting unsustainable behaviour (push measures). Furthermore, integrated strategies addressing both land use and transport are more effective than isolated measures. The results call for an effective system of regional planning.

7. CONCLUSIONS

Initially, the ILUMASS model started simulating everything by microsimulation. The project was driven by the belief that microscopic modelling allows to improve any kind of simulation by representing individual behaviour more realistically. The project finished with a comprehensive simulation model representing all steps from land use over trip generation and trip distribution to environmental impacts by microscopic modelling. After completing the ILUMASS project the group at University of Dortmund decided to move one step back and to replace parts of the microsimulation with simpler, fast-running aggregate modules. As a result, land use and environmental impacts are simulated microscopically, whereas transport is represented more aggregate.

Several reasons led the Dortmund group to abandon the pure microsimulation approach. The motivation for this step may be summarised by four concerns: run time, empirical deficiencies, ethical considerations, and stochastic variability.

Run time may develop to be one of the key issues for model development. Whereas in natural sciences it is common to simulate processes where the run time is larger than the simulated process in reality, in urban analysis it is imperative to get simulation results long before the simulated period passed in reality. If, for instance, a model run takes three weeks the model's success is likely to be jeopardized, even if the simulated period covers several decades. Each model run serves to improve the model by eliminating programming errors, setting adjustment coefficients, or improving model performance. Thus, a short model run time is necessary to allow the execution of many runs before the model is applied for policy advice. Microsimulation tends to increase run times as the treatment of individuals demands more computing power than dealing with groups. Hence, the reduction of microsimulation to those areas that are of particular interest improves run times. As the Dortmund group focussed on land use policies, it was an obvious decision to reduce the level of detail in transport. Others who are interested in, for instance, traffic light improvements, probably would reduce the level of detail on the land use side. Many model developers agree that a run time of one night at a maximum is acceptable. As efficiency was one of the higher priorities for this model, a run time of approximately one and a half hour on a high-level PC could be achieved. This comparatively short run time allowed to complete hundreds of model runs to improve the overall performance of the model.

Empirical constraints are another important reason to limit the level of detail in urban simulations. Rarely, data availability fulfils all researchers' dreams. Instead, aggregate data with occasional microscopic sample data are all that is available for research purposes. Section 5.1 gave some insight how available aggregate data may be used to generate synthetic micro data. However, the generation and the subsequent application of micro data are limited. Sometimes, theoretical insight is too weak to dig deeper into detail. For instance, if households are distinguished by too many life style groups, the simulation becomes arbitrary as both data and theoretical knowledge is unavailable at that level of detail. Certainly, there are methods to survey ever more detailed data. However, at some point the efforts and costs of gathering more detailed data are not awarded by equivalent model improvements.

This is closely related to the third limitation of microsimulation, ethical considerations. The limitation of data availability may be unfortunate for some modelling efforts. However, that not all details of human lives are exposed even for the best-intended research purposes is highly desirable to protect individual privacy.

Stochastic variability is another aspect to consider carefully in microsimulation. If the number of individuals simulated is not large enough, the random deviation of every model run is considerable. Aggregate models commonly simulate shares of a group that undergo some change and therefore manage to work without random-based selections. Microsimulation is only a valid method if the number of simulated individuals in every analysed zone is very large, as the stochastic variability is levelled out by a great number of selections.

This discussion of the limits of microsimulation should not be understood as a dismissal of microsimulation in general. Without doubt, microscopic modelling offers a great potential to urban simulation in areas where aggregate models fail, such as the simulation of environmental feedback or the simulation of spatial interaction at the individual level. However, every simulation task should be analysed carefully to determine the level of detail that is appropriate. This calls for a balanced design between aggregate and microscopic modelling. The entire microsimulation of all tasks is not the ultimate goal. Instead, every simulation module has a most suitable level of detail.

Moreover, every simulation task has an optimal level of substance, spatial detail and frequency to be simulated. The substance should be limited to the level of detail that can be based on theory and empirical evidences and is sufficient for the simulation task. For instance, household income can be grounded on sufficient theory and data and is relevant for many transport and housing decisions. Political affiliation, in contrast, seems to have a minor impact on relocation decisions or travel behaviour. A simplification in this regard appears appropriate for most simulation tasks. The necessary spatial resolution needs careful consideration, too. Whereas the simulation of environmental feedback demands a fine resolution to capture differences between a noisy arterial and a quiet backstreet two blocks apart from each other, other aspects, such as accessibility or image, can be analysed with a coarser resolution, as the differences between neighbouring blocks are minimal. And finally, the temporal aspect calls for a careful selection of how often certain modules are run. Depending on the simulation task some models need to be executed every year, whereas for other modules it is sufficient to be run every third or fifth year. Hence, model developing requires a careful consideration to find an optimum level of substantive, spatial and temporal resolution.

8. LITERATURE

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