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DESCRIPTION OF THE DORTMUND REGION MODEL

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Foreword

The International Study Group on Land-Use Transport Interaction (ISGLUTI) was founded in 1980 by the Transport and Road Research Laboratory of the UK to conduct comparative simulations of potential policies to influence the land-use transport interaction in urban regions. Membership in the group includes research groups of eight countries. In a first phase, each participating group uses its own model with the data the model was calibrated with to model a common set of policies. For a second phase, the exchange of models and data between the groups is envisaged.

The following model description presents the Dortmund region model used by the Dortmund group to simulate the land-use interaction in the Dortmund urban region as written in response to a questionnaire prepared by the ISGLUTI to collect material for a joint volume of model descriptions. It represents the model development as of May 1983.

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2 Characteristics of the Model

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2(i) Type of Model

The Dortmund model is a recursive simulation model, i.e. can be described as predictive and quasi-dynamic. Except in the transport submodel, no equilibrium assumptions are made, in fact the model never arrives at a general equilibrium. Most parts of the model are deterministic, however, the housing market submodel is a stochastic micro simulation.

Besides the base year data, the model accepts three kinds of exogenous inputs:

a) Regional forecasts of employment by sector for the total region and of immigration into and outmigration out of the region.

b) Demographic, monetary, and technological parameters specifying long-term socioeconomic and technological trends originating outside of the region.

c) Localized and time-sequenced policies in the fields of land-use planning (zoning), housing construction, industrial development, public infrastructure, and transport. Except the land use plan, policy inputs are optional.

Subject to these exogenous inputs, the model endogenously predicts for each simulation period:

a) the traffic pattern,
b) aging of population, households, jobs, and buildings,
c) relocation and new construction of workplaces,
d) demolition, rehabilitation, and new construction of housing,
e) intraregional migration.

Where present, exogenous policy inputs have precedence over endogenous allocations.

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2(ii) Model Theory

The model is eclectic with respect to theory. Its major theoretical foundation is utility maximization, but this is elaborated by a variety of assumptions about behaviour with incomplete information and under uncertainty such as elimination by aspects, satisficing, adaptation, and learning.

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2(iii) Aggregation Level

The model is aggregate as it uses classified, not individual, data throughout. The following cross-classifications are used (number of categories in brackets):

a) Population
- nationality (2)
- sex (2)
- age group (20)

b) Labour Force/Unemployed
- skill level (4)

c) Households[1]
- nationality (2)
- age of head (3)
- income group (4)
- size (5)

d) Jobs/Workplaces
- industrial sector (40)

e) Dwellings[1]
- type of building (2)
- tenure (3)
- quality (4)
- size (5)

f) Public Facilities
- facility type (40)

g) Land Use
- land use category (30)

h) Transport
- trip purpose (4)
- income group (4)
- mode (3)

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1) Where households and dwellings are cross-classified together, 30 household types and 30 dwelling types aggregated from the above 120 household types and 120 dwelling types, respectively, are used.

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2(iv) Space

The Dortmund region model constitutes the second level of a three-level spatial model hierarchy between a macroanalytic multiregional economic model of the state of Nordrhein-Westfalen and a microanalytic model of land use development within the city limits of Dortmund.

The study area of the Dortmund region model is the "urban region" of Dortmund defined as the commuting catchment area of Dortmund. It consists of Dortmund itself (pop. 610,000) with its 12 urban districts and 18 communities surrounding it. The 12 urban districts of Dortmund are relatively homogenous in size, ranging in population between 40,000 and 60,000, while the surrounding communities vary considerably in population between about 15,000 (Holzwickede) and over 400,000 (Bochum). The whole study region has a population of about 2.3 million.

The 12 urban districts of Dortmund and 18 surrounding communities constitute the 30-zone spatial system of the model. All base year data and all model results refer to these 30 zones or aggregates thereof.

The 30 zones are spatially linked by two transport networks, one representing the public transport network, the other representing the road network. The networks are coded by link, link data containing information such as length, travel time or speed, lines and frequency of service (public transport only). Each zone is connected to both networks by at least one link.

2(v) Time

The model proceeds in discrete time intervals or periods from a base year to a planning horizon. Typically, the duration of a period is two years. Up to ten periods, or 20 years, can be simulated in one run.

Like in all recursive models, in this model the end state of one period equals the initial state of the next one. Each period starts with a description of the state of the system at the beginning of the period. Based on this (outdated) information, the process leading from initial to end state is modelled. This is the implied one-period lag characteristic to recursive models. However, in some submodels information updated during the current period is applied. In this case, the sequence in which the submodels are processed is critical. Occasionally, a longer delay using information generated in previous periods is modelled.

During a simulation run, the model moves back and forth between "state description" parts (referring to a point in time) and "process description" parts (referring to a time interval). If n is the number of periods simulated, n process description parts and n+1 state description parts are executed.

The transport submodel is part of the "state description" part of each period (because it models the traffic pattern on a particular day). All land use submodels are part of the "process description" part of each period (because they model change processes occurring over the whole period such as aging, demolition, construction, migration, etc.).

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2(vi) Special Features

The Dortmund model differs from other predictive land use/ transport models by not being a spatial interaction or Lowry type model. It departs from the assumption that residential, retail, or service location is effected via the destination choice of workers or shoppers during work-to-home or shopping trips.

Instead, the model treats location and trip choice in separate, but linked submodels:

- Location decisions are primary. Households looking for a dwelling or housing investors or enterprises looking for a site select from a given supply of flats, houses, or buildable land considering relevant attributes such as size, comfort, neighbourhood quality, accessibility, or rent or price. Transport costs enter these calculations as one item among others, and in lagged and aggregate form as accessibility indices. Location decisions occur over a time interval and result in an end-of-period distribution of population and employment.

- Transport decisions are secondary to location decisions. They are made subject to a given distribution of activities (origins and destinations) at the beginning or end of the simulation period. The resulting travel pattern gives rise to the accessibility indices to be used in location decisions by households, investors, and enterprises during the subsequent period.

The conceptual separation of land use and transport decisions permits modelling housing search, residential, industrial, and commercial location as well as travel destination, mode, and route choice as occurring on separate, but interdependent urban markets. These markets are linked by lagged information, but never need to be in general equilibrium.

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3 Representation of Land Use

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3(i) Population and Households

Population is represented in the model in two ways:

a) as a population of individuals classified by

- nationality (native, foreign),
- sex,
- age (20 five-year age groups),

b) as a distribution of households classified by

- nationality (native, foreign),
- age of head (16-29, 30-59, 60+ years),
- income (low, medium, high, very high),
- size (1, 2, 3, 4, 5+ persons.

The household distribution (b) is collapsed to up to 30 more aggregate household types for use in the occupancy matrix, which links households with dwellings.

The economically active part of the population is represented as either employed or unemployed labour force at the place of residence classified by four skill levels, which correspond to the four household income groups.

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3(ii) Household Formation

The population submodel consists of two distinct but interrelated parts:

a) The aging submodel projects the population of individual persons by one simulation period, including births and deaths, on the basis of time-invariant life tables and dynamic, age-specific and spatially disaggregate fertility projections, exclusive of migration.

b) The household formation submodel projects a distribution of households by one simulation period, including demographic changes of household status such as birth, aging, death, marriage, and divorce, death of child, marriage of child, new household of child, or relative joins household, as well as change of nationality and income. The household formation submodel is a semi-Markov model with transition rates either inferred from the individual person demographic model or exogenously specified.

In each simulation period, the results of both projections are reconciled with respect to the total number of persons generated.

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3(iii) Income Groups

The four household income groups used in the model are defined in terms of BAT (Federal Employment Salary Regulations) levels as follows:

1 Households having no or a very low earned income below the BAT; households which live on welfare or are supported by relatives; students, apprentices. In 1970, these households represented about 3.6 percent of all households in the region.

2 Households having a low to medium income (equivalent to BAT VI and less). These households consist of blue collar and clerical white collar workers and represent about 82.7 percent of all households.

3 Households having a medium to high income (equivalent to BAT III-V). These households consist of medium grade white collar workers and public servants and represent about 10.1 percent of all households.

4 Households having a high to very high income (equivalent to BAT II and higher). These households earn their income by managerial and professional work and represent about 3.8 percent of all households.

At the beginning of each simulation period, disposable incomes and housing, shopping, and transport budgets of these household income groups are updated according to exogenously specified projections. Housing budgets include housing allowances and other public subsidies and are therefore different for owner-occupiers and renters. Transport budgets include expenditures for trips as well as for cars.

Labour force participation affects household incomes in the following way. Unemployment means that a household is dropped one income group, while new employment means that it is promoted by one income group, see 3(xv).

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3(iv) Supply of Land

Land is represented in the model by 30 land use categories, ten of which refer to built-up areas:

1. residential, up to 3 floors
2. residential, up to 5 floors
3. residential, high rise
4. residential and commercial
5. commercial and light industry
6. industrial
7. vacant commercial and industrial
8. public facilities
9. farm buildings
10. construction sites

The other 20 land use categories include various kinds of land use such as roads, railways, green space, woodland, and agriculture.

In addition, the model contains an internal representation of a land use or zoning plan specifying for each zone the amount of land designated to be converted from one land use category to another in a particular year of the simulation. For built-up areas, also the maximum density (amount of floorspace per unit of land) is specified in the zoning plan. Each kind of building use (residential by dwelling type or industrial or commercial by sector) is permitted on only a subset of land use categories 1 to 10 according to the zoning laws.

To determine the capacity or supply of land for a particular building use in a particular zone, the model searches the zoning plan for vacant land suitable for that building use. Under certain restrictions, in zones of high demand additional capacity may become available by demolition or conversion of existing buildings. The user may modify the zoning plan and thus impose andy desired constraint on the amount of land to be released for development.

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3(v) Land Utilization and Infrastructure Costs

Land is utilized in the model as and when buildings are being built and thus is a direct consequence of housing location, see 3(viii), and industrial location, see 3(xi).

This means that the model contains no separate submodel of the urban land market. In particular, the competitive bidding of different land uses for land is not explicitly modelled. Instead it is assumed that where two land uses bid for a piece of land, the more profitable land use will normally win. To account for this, the various land use allocation submodels are processed sequentially in the order of decreasing profitability, with average productivity taken as a proxy for profitability in the case of industrial sectors, and average rent in the case of dwelling types.

At first, the units (dwellings or workplaces) allocated to a particular piece of land in a particular zone are converted into floorspace and then into land required in accordance with the maximum density specified for that land in the zoning plan. If the land formerly was in a built-up area, it is cleared of any existing buildings prior to being released for development. If it was not formerly developed, e.g. agricultural, an appropriate amount of land is set aside for local access roads. However, the costs of such access roads and of other infrastructure related to the development are not calculated.

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3(vi) Land Prices

The model contains two simple mechanisms to update land prices from period to period.

The first land price submodel inflates all land prices according to a regionwide, exogenously specified land price inflation rate.

The second land price submodel modifies the results of the first one in response to observed demand. For each land use category in each zone, it increases or decreases the inflated land price as a function of the percentage of the total supply of land (cleared or vacant) that was actually developed and utilized during the current simulation period following exogenously specified elasticity curves.

No attempt is made to establish equilibrium land prices within a simulation period. The next adjustment of land prices occurs only in the subsequent period.

3(vii) Migration

In the migration submodel, intraregional migration decisions of households are simulated as search processes on the housing market. Thus the migration submodel is at the same time a housing market model. In the migration submodel, the more aggregate 30 household types and 30 housing types, see 2(iii) and 3(i), are used.

Technically, the migration submodel is a Monte Carlo micro simulation of a sample of representative housing market transactions. However, it differs from other "list-oriented" micro simulations in that (a) sampling and aggregation are part of the simulation and (b) stocks (households and dwellings) are classified, i.e. aggregate, data.

A market transaction is any successfully completed operation by which a migration occurs, i.e. a household moves into or out of a dwelling or both. A market transaction has a sampling phase, a search phase, a choice phase, and an aggregation phase:

- In the sampling phase, a household looking for a dwelling or a landlord looking for a tenant is sampled for being simulated.
- In the search phase, the household looks for a suitable dwelling, or the landlord looks for a tenant.
- In the choice phase, the household decides whether to accept the dwelling or not.
- In the aggregation phase, all necessary changes of households and dwellings resulting from the transaction, multiplied by the sampling factor, are performed.

The sampling phase and the search phase are controlled by multinomial logit choice functions. For instance, in the case of a household looking for a dwelling,

$$p_{k|hi} = \frac{R_{hki} \exp[-\alpha_h^h u_{hki}^h(t)]}{\sum\limits_k R_{hki} \exp[-\alpha_h^h u_{hki}^h(t)]} \qquad (3.1)$$

is the probability that of all households of type h living in zone i, one occupying a dwelling of type k will be sampled for simulation,

$$p_{i'|hki} = \frac{\sum\limits_{k'} D_{k'i'} \exp[\beta_h^m u_{hii'}^m(t)]}{\sum\limits_{i'} \sum\limits_{k'} D_{k'i'} \exp[\beta_h^m u_{hii'}^m(t)]} \qquad (3.2)$$

is the probability that the household searches in zone i' for a new dwelling, and

$$p_{k'|hkii'} = \frac{D_{k'i'} \exp[\gamma_h^h u_{hk'i'}^h(t)]}{\sum\limits_{k'} D_{k'i'} \exp[\gamma_h^h u_{hk'i'}^h(t)]} \qquad (3.3)$$

is the probability that it inspects a dwelling of type k' there before making a choice. In these equations, R_{hki} is the number of households of type h living in a dwelling of type k in zone i, and $D_{k'i'}$ is the number of vacant dwellings of type k' in zone i'. The u_{hki}^h and the $u_{hii'}^m$ are two different kinds of utility measures expressing the attractiveness of a dwelling or a zone for a household considering a move. They are discussed in 3(x). Note that the two utilities carry the time label t, i.e. are unchanged since the beginning of the simulation period, while R_{hki} and $D_{k'i'}$ are continuously updated during the simulation.

In the choice phase, the household decides whether to accept the inspected dwelling or not. It is assumed that it behaves as a satisficer, i.e. that it accepts the dwelling if this will improve its housing situation by a considerable margin. Otherwise, it enters another search phase to find a dwelling, but after a number of unsuccessful attempts it abandons the idea of a move. The amount of improvement necessary to make a household move is assumed to depend on its prior search experience, i.e. go up with each successful and down with each unsuccessful search. In other words, households are assumed to adapt their aspiration levels to supply conditions on the market.

The results of the migration submodel are intraregional migration flows of households (including starter households and inmigrant and outmigrant households) by household type between dwellings by type in the zones.

3(viii) Housing Supply

Housing is represented in the model as a distribution of dwellings classified by

- type of building (single-family, multi-family)
- tenure (owner-occupied, rented, public)
- quality (very low, low, medium, high)
- size (1, 2, 3, 4, 5+ rooms)

This housing distribution is collapsed to up to 30 more aggregate housing types for use in the occupancy matrix, which links dwellings with households.

Changes of the housing stock in the zones may occur in the model in four ways:

a) Filtering

In each period, a portion of the housing stock is assumed to filter down the quality scale, i.e. to deteriorate by aging, eventually leading to decay and demolition unless efforts to maintain and repair buildings are undertaken. The housing filtering submodel is analogous to the household formation submodel, see 3(ii), in that it projects a distribution of dwellings by one simulation period in a semi-Markov model with exogenously specified transition rates. Because of the association of households with dwellings in the occupancy matrix, the household and housing projection submodels are combined in a common submodel.

b) Maintenance/Upgrading

Landlords are assumed to invest into their housing stock if by doing so they can expect to raise their profit. The proportion of dwellings upgraded in each period is calculated for each dwelling type in each zone as a function of the expected rent increase in that submarket after improvement. As the eventual rent increase is not known at this point in time, the landlords employ a simple rent expectations model based on vacancy rates at the beginning of the simulation period. The elasticity curve controlling landlord investment behaviour is exogenous.

Filtering and maintenance/upgrading work in opposite directions. Their net effect may result in an overall deterioration or improvement of the housing quality in a zone.

c) Public Housing

The user may specify major changes of the housing stock in particular zones and years exogenously. This device is useful for entering large public housing and rehabilitation projects.

d) New Housing Construction

The submarkets of the housing construction submodel are the housing types of the aggregate (30-type) housing classification, or rather a subset of them, as only good quality housing is assumed to be built. The demand for new housing of type k to be built during the period from t to t+1, $D_k^n(t,t+1)$, is estimated by the model using a similar rent expectations model as in the maintenance/upgrading submodel. The housing demand thus estimated is allocated to vacant residential land, see 3(iv), by a multinomial logit model:

$$D_{k\ell i}^n(t,t+1) = \frac{C_{k\ell i}^d \exp[\gamma_k^d\, u_{k\ell i}^d(t)]}{\sum\limits_i \sum\limits_\ell C_{k\ell i}^d \exp[\gamma_k^d\, u_{k\ell i}^d(t)]}\, D_k^n(t,t+1) \qquad (3.4)$$

where $D_{k\ell i}^n(t,t+1)$ is new dwellings of type k built on land use category ℓ in zone i between t and t+1, and $C_{k\ell i}^d$ is the capacity of that vacant land for dweelings of type k. $C_{k\ell i}^d$ bears no time label as it is successively reduced during the simulation period by land uses with similar land requirements, see 3(v). The utility $u_{k\ell i}^d$ expresses the attractiveness of land use category ℓ in zone i for dwellings of type k:

$$u_{k\ell i}^d = \left[u_{ki}^d\right]^{w_k^{di}} \left[u_{k\ell}^d\right]^{w_k^{d\ell}} \left[u_{k\ell i}^{dp}\right]^{w_k^{dp}} \qquad (3.5)$$

where u_{ki}^d is the attractiveness of zone i as a location for housing type k, $u_{k\ell}^d$ is the attractiveness of land use category ℓ for housing type k, and $u_{k\ell i}^{dp}$ is the attractiveness of the land price of land use category ℓ in zone i in relation to the expected rent or price of the dwelling. The w_k^{di}, $w_k^{d\ell}$, and w_k^{dp} are multiplicative weights adding up to unity. The component utilities are similarly constructed as the components of the housing utility u_{hki}^{h}, see 3(x). Like all utilities used in the model, $u_{k\ell i}^{d}$ remains unchanged during the simulation period as calculated at time t.

Dwellings built during a simulation period utilize land immediately, but become available to the housing market only in the subsequent period.

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3(ix) Housing Prices/Rents

The price of housing is represented in the model in the form of monthly rent per dwelling unit by type, in the case of owner-occupied houses or flats in the form of imputed rents.

The model contains three different mechanisms to update housing prices/rents from period to period:

The first rent submodel inflates all rents according to a regionwide, exogenously specified rent inflation rate.

The second rent submodel adjusts rents in particular submarkets whenever new or modernized dwellings are released to the housing market. Modernized dwellings are more expensive than before, and new dwellings are larger <u>and</u> more expensive. The resulting submarket rent is an average of old and new rents.

The third rent submodel modifies the results of the first two in response to demand observed on the housing market. For each submarket, i.e. each combination of dwelling type and zone, it increases or decreases the inflated rent as a function of the vacancy rate in that submarket <u>after</u> the housing market simulation following exogenously specified elasticity curves.

No attempt is made to establish equilibrium rents on the housing market <u>within</u> a simulation period. Rents remain fixed during the market clearing process, see 3(vii), and are adjusted only in the next period.

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3(x) Attractiveness of Housing Areas

In this model, residential choice by households occurs on the housing market, and the housing market submodel is the migration submodel. Consequently, residential choice has been discussed in 3(vii).

This section will be used to show how the attractiveness measures u^h_{hki} and $u^m_{hii'}$ of equations 3.1-3.3 are constructed.

The attractiveness of a dwelling of type k in zone i for a household of type h, u^h_{hki}, is a weighted aggregate of housing attributes:

$$u^h_{hki} = \left[u^h_{hi}\right]^{w^{hi}_h} \left[u^h_{hk}\right]^{w^{hk}_h} \left[u^{hp}_{hki}\right]^{w^{hp}_h} \tag{3.6}$$

where u^h_{hi} is the attractiveness of zone i as a housing location for household type h, u^h_{hk} is the attractiveness of housing type k for household type h, and u^{hp}_{hki} is the attractiveness of the rent or price of the dwelling in relation the the household's housing budget. The w^{hi}_h, w^{hk}_h, and w^{hp}_h are multiplicative importance weights adding up to unity. Both u^h_{hi} and u^h_{hk} are themselves multiattribute encompassing relevant attributes of the neighbourhood or the dwelling:

$$u^h_{hi} = \sum_n w^{hi}_{hn}\, v^{hi}_{hn}\left[f^{hi}_{hn}(\underline{x}_i, \underline{u}^a_{hi})\right] \tag{3.7}$$

$$u^h_{hk} = \sum_n w^{hk}_{hn}\, v^{hk}_{hn}\left[f^{hk}_{hn}(\underline{x}_k)\right] \tag{3.8}$$

where n, n = 1,...,N indicates attribute n. The w^{hi}_{hn} and w^{hk}_{hn} are importance weights adding up to unity, the $v^{hi}_{hn}(.)$ and $v^{hk}_{hn}(.)$ are value functions mapping attributes to utility, and the $f^{hi}_{hn}(.)$ and $f^{hk}_{hn}(.)$ are generation functions specifying how to calculate attributes from one or more elements of vectors $\underline{x}_i$ or $\underline{x}_k$ of raw attributes of zone i or dwelling type k, or accessibility indices $\underline{u}^a_{hi}$ of zone i, see below. The housing price attractiveness u^{hp}_{hki} is calculated as

$$u^{hp}_{hki} = v^{hp}(p^h_{ki}/y^h_{hk}) \tag{3.9}$$

where p^h_{ki} is rent, or imputed rent, of dwelling type k in zone i, and y^h_{hk} is the monthly housing budget of household type h for this dwelling type. The housing budgets include housing allowances and other public subsidies and are therefore different for rented and owner-occupied dwellings.

The $\underline{u}^a_{hi}$ are household-type specific vectors of accessibility indices describing the location of zone i in the region:

$$u^a_{hni} = \sum_j \sum_{m \in M_h} \frac{W_{nj}\ \exp(\beta^a_n\ u^t_{hijm})}{\sum_j \sum_{m \in M_h} W_{nj}\ \exp(\beta^a_n\ u^t_{hijm})}\ u^t_{hijm} \tag{3.10}$$

or

$$u^a_{hgi} = \sum_j \sum_{m \in M_h} \frac{t_{hgijm}}{\sum_j \sum_{m \in M_h} t_{hgijm}}\ u^t_{hijm} \tag{3.11}$$

Both accessibilities are expressed in terms of mean trip utility, i.e. as a weighted average of trips from i to j using mode m with trip utility u^t_{hijm} for household type h. See 4(v) for a discussion of trip utilities. In the first form of accessibility, the weights are potential trips to activities or facilities W_{nj} of type n in j, the second accessibility uses trips of purpose g calculated in the transport submodel, t_{hgijm}, see 4(ix). The set M_h includes all transport modes accessible to household type h, depending on its car ownership level, see 4(vii).

The attractiveness measure $u^m_{hii'}$ used in equation 3.2 is a relational utility describing the attractiveness of a zone i' as a new housing location for a household of type h now living in zone i and working in any of the zones near i, hence it is called "migration utility":

$$u^{m}_{hii'} = \left[\sum_{j}\sum_{m\in M_h} \frac{t_{h1ijm}}{\sum_{j}\sum_{m\in M_h} t_{h1ijm}} u^{t}_{hi'jm}\right]^{w^c_h}$$

$$\left[\sum_{m\in M_h} \frac{t_{h3ii'm}}{\sum_{m\in M_h} t_{h3ii'm}} u^{t}_{hii'm}\right]^{w^s_h} \qquad (3.12)$$

where t_{hgijm} and u^{t}_{hijm} are again trips of purpose g and the corresponding trip utilities. The first part of the expression is the expected utility of a work trip (g = 1) from the new housing zone i' to all possible old work zones j after the move, the second part evaluates the utility of a social or service trip (g = 3) between the old and the new housing zone. The w^c_h and w^s_h are multiplicative weights adding up to unity.

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3(xi) Industrial Location

The industrial location submodel makes no distinction between basic and nonbasic industries, i.e. all sectors are located or relocated endogenously subject to sectoral employment projections for the whole region. However, the location of employment of all sectors may also be controlled exogenously by the user in order to reflect major events such as the location or closure of large plants in particular zones.

Each of the 40 industrial sectors of the model, see 3(xiii), is treated as a separate submarket. The model starts from existing employment $E_{s\ell j}(t)$ of sector s situated on land use category ℓ in zone j at time t. There are nine different ways for $E_{s\ell j}$ to change during a simulation period:

a) Sectoral Decline

Declining industries make workers redundant. This occurs not necessarily at the same rate all over the region, but is more likely where locational conditions are less favorable:

$$E^{rs}_{s\ell j}(t,t+1) = \frac{E_{s\ell j}(t)\ \exp[-\alpha^{e}_{s}\ u^{e}_{s\ell j}(t)]}{\sum\limits_{j}\sum\limits_{\ell} E_{s\ell j}(t)\ \exp[-\alpha^{e}_{s}\ u^{e}_{s\ell j}(t)]}\ [E_{s}(t+1)-E_{s}(t)] \qquad (3.13)$$

is the number of workers of sector s made redundant on land use category ℓ in zone j between t and t+1. $E_s(t)$ indicates total employment of sector s in the region and $E_s(t+1)$ is the exogenous projection of total regional employment for time t+1. The utility $u^{e}_{s\ell j}$ expresses the attractiveness of land use category ℓ in zone j for industry s, see below. $E^{rs}_{s\ell j}$ is set to zero for growing industries.

b) Relocation

Some industries are very stationary, while others easily move from one location to a more attractive one. If r^{e}_{s} is a sectoral mobility rate,

$$E^{rr}_{s\ell j}(t,t+1) = \frac{E_{s\ell j}(t)\ \exp[-\alpha^e_s\ u_{s\ell j}(t)]}{\sum_j \sum_\ell E_{s\ell j}(t)\ \exp[-\alpha^e_s\ u_{s\ell j}(t)]}\ r^e_s\ E_s(t) \qquad (3.14)$$

is the number of workplaces relocated from land use category ℓ in zone j during the period. The mobility rate r^e_s is exogenous.

c) Lack of Building Space

In most sectors, mechanization and automation tend to increase the building floorspace per workplace. Accordingly, in each period, a number of jobs $E^{rb}_{s\ell j}$ have to be relocated because of lack of space:

$$E^{rb}_{s\ell j}(t,t+1) = E_{s\ell j}(t)\left[1- \frac{b_{sj}(t)}{b_{sj}(t+1)}\right] -E^{rs}_{s\ell j}(t,t+1) \qquad (3.15)$$

where $b_{sj}(t+1)$ is the projected floorspace per workplace of sector s in zone j at time j+1, which will be always greater or equal to its value at time t. Where redundancies exceed relocations due to lack of space, $E^{rb}_{s\ell j}$ is set to zero.

d) Large Plants

The user may specify the location or removal of any number of jobs of any sectors or groups of sectors in any zone or year exogenously. New jobs thus generated are called $E^{nx}_{s\ell j}$, redundancies $E^{rx}_{s\ell j}$.

e) New Jobs in Vacant Buildings

Declining sectors or relocating firms leave buildings vacant that may be used by other industries. For this purpose, the 40 sectors have been divided into groups with similar space requirements. The total demand for new workplaces in the region is

$$\begin{aligned} E^n_s(t,t+1) = {} & E_s(t+1)-E_s(t) \\ & + \sum_j \sum_\ell \Big[E^{rs}_{s\ell j}(t,t+1)+E^{rr}_{s\ell j}(t,t+1)+E^{rb}_{s\ell j}(t,t+1) \\ & +E^{rx}_{s\ell j}(t,t+1)-E^{nx}_{s\ell j}(t,t+1)\Big] \end{aligned} \qquad (3.16)$$

If this demand is less than the total supply of suitable floorspace, it is allocated to vavant floorspace with the following allocation function:

$$E^{nv}_{s\ell j}(t,t+1) = \frac{C^{ev}_{s\ell j} \exp[\gamma^e_s u^e_{s\ell j}(t)]}{\sum_j \sum_\ell C^{ev}_{s\ell j} \exp[\gamma^e_s u^e_{s\ell j}(t)]} E^n_s(t,t+1) \qquad (3.17)$$

where $C^{ev}_{s\ell j}$ is the capacity of existing buildings on land use category ℓ in zone j for workplaces of sector s. $E^{nv}_{s\ell j}$ is the number of jobs accommodated in this way.

f) New Jobs in New Buildings

For any remaining demand, new industrial or commercial buildings have to be provided. This demand is allocated to vacant industrial or commercial land, see 3(iv), with the allocation function

$$E^{nc}_{s\ell j}(t,t+1) = \frac{C^{en}_{s\ell j} \exp[\gamma^e_s u^e_{s\ell j}(t)]}{\sum_j \sum_\ell C^{en}_{s\ell j} \exp[\gamma^e_s u^e_{s\ell j}(t)]} \left[E^n_s(t,t+1) - \sum_j \sum_\ell E^{nv}_{s\ell j}(t,t+1)\right] \qquad (3.18)$$

where $E^{nc}_{s\ell j}(t,t+1)$ are new workplaces of sector s built on land use category ℓ in zone j between t and t+1. $C^{en}_{s\ell j}$ is the current capacity for such workplaces, since it is continuously reduced during the simulation period, it bears no time label.

The utility $u^e_{s\ell j}$ used in equations 3.13, 3.14, 3.17, and 3.18 is the attractiveness of land use category ℓ in zone j for sector s and has three components:

$$u^e_{s\ell j} = \left[u^e_{sj}\right]^{w^{ej}_s} \left[u^e_{s\ell}\right]^{w^{e\ell}_s} \left[u^{ep}_{s\ell j}\right]^{w^{ep}_s} \qquad (3.19)$$

where u^e_{sj} is the attractiveness of zone j as a location for sector s, $u^e_{s\ell}$ is the attractiveness of land use category ℓ for sector s, and $u^{ep}_{s\ell j}$ is the attractiveness of the land price of land use category ℓ in zone j in relation to the expected profit of economic activity s. The w_s^{ej}, $w_s^{e\ell}$, and w_s^{ep} are multiplicative importance weights adding up to unity. The three component utilities are similarly constructed as the components of the housing utility u_{hki}^h, see 3(x). Like all utilities in the model, $u_{s\ell j}^e$ remains unchanged during the simulation period as calculated at time t.

The price or rent of industrial or commercial buildings is not represented in the model.

g) Demolition of Existing Buildings

The land capacity $C_{s\ell j}^{en}$ is normally taken as being fixed as specified in the zoning plan. If a piece of land formerly was in a built-up area, its utilization implies the demolition of existing buildings. In addition, under certain restrictions in zones of high demand the capacity $C_{s\ell j}^{en}$ may be extended by demolition of existing buildings of less profitable building uses to represent displacement processes going on within existing neighbourhoods. All workplaces or dwellings displaced by demolition during a simulation period are replaced in the same period by iterating the industrial and residential submodels several times.

h) Conversion of Existing Dwellings

In the case of service workplaces, the capacity of a zone may also be extended by conversion of existing dwellings into offices where the demand for office space is high in relation to supply to represent the displacement of dwellings by offices observed within or near the CBD. All dwellings converted to offices during a simulation period are replaced in the same period by iterating the industrial and residential location submodels several times.

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3(xii) Employment Choice

The present version of the model contains no change-of-job submodel. In effect, workers "choose" a job in the doubly constrained work trip model, see 4(ix). In the housing market submodel, see 3(vii), all moving households are assumed to retain their jobs.

Both assumptions are unsatisfactory and will be abandoned in future work.

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3(xiii) Disaggregation of Employment

Employment and industrial and commercial buildings are represented in the model by 40 industrial sectors following the industrial classification by the Federal Statistical Office:

industry group	model sectors	industries
0	1	agriculture, forestry
1	2-3	energy, mining
2	4-30	manufacturing
2	31	small industry, crafts
3	32	building industry
4	33-34	wholesale, trading
4	35	retail
5	36	transport, communications
6	37	banks, insurances
7	38-39	other services
8/9	40	public service

Jobs are associated with skills by skill profiles specifying for each industry group the distribution of the four skill levels among its workers.

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3(xiv) Shopping

Retail is treated like any other economic sector in the model, except that the mobility rate r_s^e, see equation 3.14 in 3(xi), is higher for retail than for other sectors, and that the zonal attractiveness u_{sj}^e, see equation 3.19 in 3(xi), for retail includes an attribute n

$$u_{sjn}^e = v_{sn}^{ej}\left[\frac{\sum_h \sum_i \sum_m t_{h2ijm}\, y_{hi}^r \;/\; E_j^r}{\sum_h \sum_i \sum_j \sum_m t_{h2ijm}\, y_{hi}^r \;/\; \sum_j E_j^r}\right] \qquad (3.20)$$

where t_{h2ijm} are shopping trips (g = 2) of household type h from residential zone i to shopping zone j using mode m, y_{hi}^r are retail expenses of a household of type h in zone i, E_j^r is retail employment in zone j, and v_{sn}^{ej} is the value function mapping attribute n to utility. This attribute indicates retail sales per retail employee in zone j expressed in units of average turnover per retail employee in the whole region.

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3(xv) Vacancies, Overcrowding, and Unemployment

Imbalances between supply and demand on the housing market and the labour market are treated in the model as follows:

a) Housing Market

Dwellings are either occupied and contained in the occupancy matrix $\underline{R}$, see equation 3.1 in 3(vii), or vacant and contained in the vacancy matrix $\underline{D}$, see equations 3.2 and 3.3 in 3(vii). With each move, an occupied dwelling becomes vacant and a vacant dwelling is occupied. Outmigrant households vacate a dwelling without occupying one, inmigrant households and starter households occupy a dwelling without leaving one vacant. New dwellings enter the market vacant. Dwellings being demolished may be occupied or vacant. During the housing market simulation, less attractive and/or too expensive dwellings are more likely to become and remain vacant. Hence the vacancy rate in a particular submarket (combination of dwelling type and zone) after the housing market simulation is an indicator of the demand for dwellings in that submarket.

Overcrowding of housing occurs when housing supply is too small or too expensive. In the first case, starter households and inmigrant households are most affected and may have to become subtenants. The second case may arise when rents go up faster than incomes and thus housing budgets, for instance in times of mass unemployment (see below). Then households have to postpone or abandon their plans to improve their housing situation or even are forced to give up their present dwelling and move into a smaller one or become subtenants. Note that vacancies and overcrowding can occur in different submarkets of the housing market at the same time.

b) Labour Market

In the absence of an employment choice submodel, see 3(xii), vacant jobs of each skill level, see 3(xiii), are assumed to be spread pro rata over the jobs of all sectors and zones.

Unemployment is the balance between the economically active population and actual employment at the place of residence. The economically active population by skill level of a zone is forecast as its previous value plus accessions minus retirements during the period using information such as the age and sex composition and the previous zonal labour force participation rate. Actual employment by skill level h at places of residence i at time t+1, $P^e_{hi}(t+1)$, is inferred from employment predicted at places of work j, $E_{sj}(t+1)$, in the industrial location submodel, see 3(xi), using the spatial information contained in the work trip matrix:

$$P^e_{hi}(t+1) = \sum_j \sum_m \frac{t_{h1ijm}}{\sum_j \sum_m t_{h1ijm}} \sum_s q^e_{sh} \, E_{sj}(t+1) \qquad (3.21)$$

where q^e_{sh} is the proportion of workers of skill level h in sector s, see 3(xiii), and t_{h1ijm} are work trips (g = 1) of workers of skill level h from i to j using mode m.

Apart from affecting the zonal unemployment rate, changes of employment at places of residence lead to changes of household incomes. It is assumed that unemployment means that a household drops from one income group to the next lower one. Conversely, new employment means that a household is promoted by one income group. This is achieved in the model by constructing for each residential zone from net changes of P^e_{hi} a matrix of transition rates between household income groups and using this matrix to update all household distributions of the zone including the occupancy matrix.

4 Representation of Transport

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4(i) Road Network and Public Transport

Transport supply is represented in the model by two explicit transport networks, public transport and road, and one implicit network, walking.

The public transport and road networks are coded as separate networks by link. Link data include the usual information such as link type, directions, length, travel time or travel speed, frequency of service and lines (public transport only). Each zone is connected with both networks by at least one access link.

The present version of the model can handle up to 1,800 two-way links (1,800 nodes) in the public transport network and 2,400 links (1,600 nodes) in the road network. Up to 8 public transport lines can run on one link, altogether 900 line combinations can be stored.

Both transport networks can be incrementally updated during a simulation by exogenously specifying time-sequenced network changes by link.

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4(ii) Modes

The three transport modes represented in the model comprise the following link types:

Walking (m = 0)

00	walking and bicycle

Public Transport (m = 1)

10	access link, internal link
11	Federal Railways, local train
12	S-Bahn (Federal Railways rapid transit)
13	U-Bahn (underground)
14	tramway
15	bus

Car/Motorcycle (m = 2)

20	access link, internal link
21	Autobahn (motorway), six-lane
22	Autobahn (motorway), four-lane
23	urban motorway, four-lane
24	urban thoroughfare, four-lane
25	urban thoroughfare, two-lane
26	urban local road, two-lane
27	rural road, two-lane

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4(iii) Time of Day

The model simulates all outgoing home-based trips during a four-hour morning peak period. Return trips and non-home-based trips are not considered.

The levels of service coded in the public transport network (train/bus frequencies) apply to this four-hour morning period. The link travel times coded in the road network refer to non-congested travel. See 4(iv) for congestion travel times.

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4(iv) Congestion and Parking

A speed-flow relationship is used to adjust link travel times of congested road links:

$$t'_{2\ell} = t^{o}_{2\ell} \left\{1+\rho \left[\frac{v_{2\ell}}{c^{v}_{2\ell}\ h^{p}\ o^{c}}\right]^{\phi}\right\} \tag{4.1}$$

In this equation, $t'_{2\ell}$ is the adjusted and $t^{o}_{2\ell}$ the uncongested travel time on link ℓ, $v_{2\ell}$ is the volume of car trips ($m = 2$) on that link during the peak period, and $c^{v}_{2\ell}$ its capacity per hour, and h^{p} is the length of the peak period in hours and o^{c} the average car occupancy. See 4(ix) for the assignment procedure.

Parking difficulties in high-density areas with limited parking facilities are taken account of by (a) a time and cost penalty for trips ending in such areas, see 4(v), and (b) a monthly cost penalty for car owners living in such areas, see 4(vii). The parking search time and parking costs of (a) are estimated as a function of parking supply vs. parking demand, the latter being based on results of the car ownership model, see 4(vii), plus additional parking requirement standards for employment, shops, services, and public facilities. The monthly costs of having a downtown garage of (b) is calculated as a fixed multiple of the short-term parking costs of (a).

4(v) Transport Costs

Monetary and non-monetary costs and benefits of trips are aggregated by the model into one single measure called trip utility:

$$u^t_{hijm} = \left[v^t_m(t^t_{ijm})\right]^{w^t_h} \left[v^c_m\left(\frac{c^t_{ijm}}{c^{to}_h}\right)\right]^{w^c_h} \qquad (4.2)$$

Here u^t_{hijm} is the utility of a trip from i to j using mode m for a household of type h, the w^t_h and w^c_h are multiplicative importance weights adding up to one, and t^t_{ijm} and c^t_{ijm} are travel time and travel cost of the trip, respectively. Travel cost is seen in relation to c^{to}_h, the amount of money the household is willing and able to pay per trip, given its car ownership level and number of trips per month, see 4(vii). The $v^t_m(.)$ and $v^c_m(.)$ are value functions mapping travel time and cost to a common utility dimension. These two monotone decreasing functions represent the only distance decay functions of the whole model. They are different for each mode to reflect characteristics of each mode not captured by the dimensions time and money. The weights w^t_h and w^c_h, however, are different for different household income groups to account for the different evaluation of time and money by people with different incomes.

Travel time and travel costs are calculated differently for each mode:

Walking (m = 0)

Because there is no explicit network of walkways contained in the model, door-to-door walking time between two zones is inferred by taking the minimum of the travel distances of the two other modes (see below), reducing it by a detour factor (because walks are more straightforward than vehicle trips), and converting it into time through division by walking speed. The costs of walks are zero.

Public Transport (m = 1)

Travel times in the public transport network are determined using a time-oriented minimum-path algorithm which adds boarding and transfer waiting time to in-vehicle travel time as a function of service frequency of the connecting line. Door-to-door travel times produced by the algorithm include the following components: access time, waiting time before boarding, in-vehicle travel time, waiting time at transfer stops (if any), terminal time. Also the travel distances of the minimum-time routes are recorded. Intrazonal travel times and distances are exogenous inputs. Travel costs of public transport trips are calculated as a flat fare plus a distance-dependent fare increment for longer trips and are reduced by a discount factor reflecting savings made by buying monthly tickets. All fare components are inflated by an appropriate inflation rate. Public transport travel times and costs remain unchanged during the traffic assignment process, see 4(ix).

Car/Motorcycle (m = 2)

Travel times on the road network are determined using a time-oriented minimum-path algorithm. Door-to-door travel times produced by the algorithm include: access time, in-vehicle time, terminal time. Travel distances of minimum-time routes are also recorded. Intrazonal travel times and distances are exogenous inputs. Car travel costs are distance-dependent out-of-pocket car operating costs divided by average car occupancy and are inflated by an inflation rate reflecting the development of petrol prices. In a final step, car travel times and costs are incremented by parking search time and parking costs at the trip ends, see 4(iv). Car travel times and costs, and thus the trip utilities of car trips, are recalculated several times during the traffic assignment process with different link loads and hence link travel times, see 4(ix).

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4(vi) Non-monetary Characteristics of Transport

The most important non-monetary characteristic of transport supply considered in the model is travel time. Frequency of public transport service is integrated into travel time in the form of waiting time. Travel time is not converted into transport cost by value-of-time coefficients, but both, travel time and travel cost, are mapped into a common utility dimension by value functions, see 4(v). Differences between modes not captured by the dimensions time and money (e.g. comfort, physical effort, reliability, safety) are reflected in different value functions for the three modes.

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4(vii) Car Ownership

The car ownership submodel estimates the number of cars owned by households as a function of household travel budgets and expected travel expenditures:

$$Q_{hi}(t) = \frac{H_{hi}(t)\ y_h^t(t) - \sum_g \sum_j \sum_m \bar{t}_{hgijm}(t)\ c_{ijm}(t)}{c^c(t)+c_i^p(t)} \qquad (4.3)$$

where $Q_{hi}(t)$ is the number of cars owned by households of income group h living in zone i at time t, $H_{hi}(t)$, having a monthly travel budget $y_h^t(t)$, and $c^c(t)$ and $c_i^p(t)$ are monthly costs of owning and parking a car in i, respectively. The $\bar{t}_{hgijm}$ are trips per month of households of type h for purpose g from i to j using mode m, and c_{ijm} are the out-of-pocket car operating costs of such trips. This equation reflects the assumption that households have to split their travel budgets between expenditures for trips and for cars.

Concurrently with car ownership levels, for each household income group in each zone, the amount of money the household is able and willing to pay given its car ownership level and number of trips is estimated as a deviation from the system mean travel cost c^{to} proportional to the deviation of the household's car ownership level from the regional average:

$$c_{hi}^{to} = c^{to} \frac{Q_{hi} / H_{hi}}{\sum_i \sum_h Q_{hi} / \sum_i \sum_h H_{hi}} \qquad (4.4)$$

where c_{hi}^{to} is the trip cost standard as used in equation 4.2 of 4(v). This equation reflects the assumption that households owning more (less) cars will also choose more (less) expensive trips.

Household travel budgets and trip cost standards are inflated by an inflation rate each period, but are taken to be fixed during the period. However, the number of trips by purpose, destination, and mode, $\bar{t}_{hgijm}$, and their costs, c_{ijm}, depend on car ownership levels, see 4(ix) and 4(iv), as do the costs of garages, c_i^p. Therefore, at first a rough approximation of trip expenditures is used to estimate initial car ownership levels and trip cost standards, and the car ownership submodel is reiterated together with the traffic assignment iterations, see 4(ix).

4(viii) Freight Transport

Freight transport is not represented in the model.

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4(ix) Transport Demand

This section has been appended to the questionnaire for Chapter 4 to permit a discussion of the separate transport demand submodel contained in the Dortmund model.

The transport demand submodel is an aggregate spatial interaction model involving the following steps:

a) Trip Generation

In a first step, initial estimates of trip origins and destinations are calculated as a function of zonal activity levels. Only home-based trips are considered. The model disaggregates trips by four trip purposes (g) and four household income groups/skill levels (h):

trip purpose g	income group/ skill level h	origin activity	destination activity
1 work	1 2 3 4	workers of skill level h	jobs of skill level h
2 shopping	1 2 3 4	households of income group h	retail employment
3 services/ social	1 2 3 4	households of income group h	service employment, population
4 school	1 2 3 4	students of households of income group h	secondary schools (classes)

The above 16 demand models are classified into "obligatory" and "voluntary" trips. Obligatory trips are work trips (g = 1) and school trips (g = 4). Their numbers, or origins, are assumed to be fixed by a daily trip rate per worker or student, respectively. Shopping trips (g = 2) and service/social trips (g = 3) are partly voluntary. Demand for such trips is elastic, i.e. depends to a certain degree on transport supply and travel budgets. Poor people can afford less cars and can make less (and cheaper) voluntary trips than rich people who can afford more cars and make more (and more expensive) trips. So trip origins for shopping and service/social trips are in the model a function of activity levels and car ownership. Car ownership, however, is a function of trip expenditures, see 4(vii), and thus of destination and mode choice, see below. Hence, the trip generation step has to be included into the iterations of the traffic assignment process, see below.

All trip rates used in the model refer to trips of more than 500 metres length, i.e. walking trips within a building or its immediate vicinity are excluded.

b) Destination and Mode Choice

Another distinction between the 16 demand models is related to constraints on destination choice. For work and school trips, destinations are fixed, so a doubly constrained model is appropriate. There are no constraints on destination choice for shopping and service/social trips, hence a production-constrained model is used.

Destination and mode choice are combined into one integrated trip distribution model for each trip purpose and household income group. However, trip origins are split with respect to car availability. The following assumptions about car availability are made:

- All cars owned by a household are available for work trips.
- Cars not used for work trips are available for shopping and service/social trips.
- Cars not used for other trips are available for school trips by students having a driver's licence.

With these assumptions, the combined destination and mode choice model is

$$t_{hgijm}(t) = \sum_{k} A_{hgki}\ B_{hgj}\ O_{hgki}(t)\ D_{hgj}(t)\ \exp[\beta_g^t\ u_{hijm}^t(t)] \tag{4.5}$$

where t_{hgijm} are trips made by households type/skill level h for trip purpose g from i to j using mode m, O_{hgki} is the number of such trips originating in i with car availability k (k = 1: car available, k = 2: no car available), and D_{hgj} are trip destinations for that kind of trips in zones j. The u_{hijm}^t are the trip utilities calculated in equation 4.2, see 4(v). A_{hgki} and B_{hgj} are balancing factors ensuring that the origin and destination constraints, where applicable, are satisfied:

$$A_{hgki} = 1 / \sum_{j} \sum_{m \in M_k} B_{hgj}\ D_{hgj}(t)\ \exp[\beta_g^t\ u_{hijm}^t(t)] \tag{4.6}$$

$$B_{hgj} = \begin{cases} 1 / \sum_{i} \sum_{k} \sum_{m \in M_k} A_{hgki}\ O_{hgki}(t)\ \exp[\beta_g^t\ u_{hijm}^t(t)] & \\ \qquad\qquad\qquad\qquad\qquad\qquad \text{for } g = 1,4 & \\ 1 \quad \text{for } g = 2,3 & \end{cases} \tag{4.7}$$

where M_k is the subset of modes accessible with car availability k. For the 8 doubly constrained models (g = 1,4), the balancing factors are determined iteratively using the RAS technique.

As an alternative to this one-parameter model, different parameters may be used for destination and mode choice. In that case, the expression $\exp[\beta_g^t\ u_{hijm}^t(t)]$ in equations 4.5-4.7 is replaced by

$$\sum_{m \in M_k} \exp[\beta_g^t\ u_{hijm}^t(t)]\ \frac{\exp[\lambda_g^t\ u_{hijm}^t(t)]}{\sum_{m \in M_k} \exp[\lambda_g^t\ u_{hijm}^t(t)]} \tag{4.8}$$

satisfying the modal share equation

$$p_{m|hgkij}(t) = \frac{\exp[\lambda_g^t \, u_{hijm}^t(t)]}{\sum_{m \in M_k} \exp[\lambda_g^t \, u_{hijm}^t(t)]} \tag{4.9}$$

c) Trip Assignment and Capacity Restraint

In the trip assignment step, trips are assigned to links ℓ of network m such that the flow volume $v_{m\ell}$ of link ℓ in m

$$v_{m\ell} = \sum_h \sum_g \sum_i \sum_j \delta_{ijm\ell} \, t_{hgijm} \tag{4.10}$$

where

$$\delta_{ijm\ell} = \begin{cases} 1 & \text{if } \ell \in r_{ijm} \\ 0 & \text{otherwise} \end{cases} \tag{4.11}$$

and $r_{ijm} = \{\ell_1, \ell_2, \ldots, \ell_R\}$ is the current minimum-path route in network m from i to j.

In the capacity restraint step, equation 4.1, see 4(iv), is used to calculate road network link travel times that correspond to link flow volumes $v_{2\ell}$.

d) Network Equilibrium

User-optimal, congestion-sensitive equilibrium of car ownership, trip generation, and destination and mode choice is approached by applying an extended version of the network equilibrium algorithm by Evans (1976). For the one-parameter model specified in equations 4.5-4.7, the extended algorithm proceeds as follows.

(1) Calculate origin and destination activities.
(2) Make initial estimates of car ownership, trip cost standards, and trip rates.
(3) Find minimum public transport paths and calculate trip utilities for public transport and walking.

(4) Set iteration counter n to zero.
(5) Set n to n+1.
(6) Find minimum paths and calculate trip utilities for car trips.
(7) Solve the 16 trip distribution models.
(8) Recalculate car ownership, trip cost standards, and trip rates. If changes are large, go to (7).
(9) Assign car trips of (7) to minimum paths of (6) and calculate new link times and trip utilities.
(10) If n = 1, go to (5).
(11) Perform line search to find a value θ^n, $0 \leqslant \theta^n \leqslant 1$, maximizing the objective function

$$\max_{\theta^n} U^n(\underline{t}^{n'}, \underline{u}^{n'}) = \sum_h \sum_g \sum_i \sum_j \sum_m t^{n'}_{hgijm} \, u^{n'}_{hijm} - \sum_h \sum_g \frac{1}{\beta^t_g} \sum_i \sum_j \sum_m t^{n'}_{hgijm} \ln t^{n'}_{hgijm} \tag{4.12}$$

where

$$t^{n'}_{hgijm} = (1-\theta^n)\, t^{n-1}_{hgijm} + \theta^n \, t^n_{hgijm} \tag{4.13}$$

$$u^{n'}_{hijm} = (1-\theta^n)\, u^{n-1}_{hijm} + \theta^n \, u^n_{hijm} \tag{4.14}$$

(12) Replace $\underline{t}^n$ by $\underline{t}^{n'}$ and $\underline{u}^n$ by $\underline{u}^{n'}$.
(13) If change of U^n over U^{n-1} is large, go to (5).
(14) Stop.

A good approximation of θ^n to avoid the line search is $\theta^n = 1/n$, i.e. giving equal weights to all successive solutions. After about four iterations, changes of the convergence criterion as well as of car ownership, trip rates, destination and mode choice tend to be sufficiently small for this kind of analysis.

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5 Interaction between Land Use and Transport

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5(i) Land Use Effects on Destination Choice

A change of land use will result in different trip origins and trip destinations in equation 4.5 of the transport submodel and thus will give rise to a different equilibrium of car ownership, trip rates, destination and mode choice, road congestion, and trip utilities.

These impacts become effective with the next execution of the transport submodel at the beginning of the subsequent simulation period.

Note that in this model destination choice does not imply any choice of location of activities, see 2(vi).

5(ii) Land Use Effects on Modal Choice

Changes in land use may affect modal choice in the transport submodel in various ways:

The overall proportion of public transport trips will increase (decrease) if, everything else being equal,

- activities (households, workers, jobs, shopping facilities) shift to zones with good (poor) public transport supply,
- household travel budgets increase slower (faster) than transport costs resulting in lower (higher) car ownership levels,
- road congestion increases (decreases) due to shifts in the location of activities.

The proportion of public transport trips from individual zones will increase (decrease) if, everything else being equal,

- the proportion of high and medium income households and thus car ownership in the zone decreases (increases),
- parking costs in the zone increase (decrease) due to changes in parking space demand or supply in the zone.

The proportion of public transport trips to individual zones will increase (decrease) if, everything else being equal,

- parking costs and search time in the zone increase (decrease) due to changes in parking space demand or supply in the zone,
- car accessibility of the zone decreases (increases) due to changes in road congestion caused by shifts in the location of activities.

The above impacts become effective with the next execution of the transport submodel at the beginning of the subsequent simulation period.

5(iii) Land Use Effects on Car Ownership

Household car ownership in the model is a function of the household travel budget, the monthly costs of owning a car, and total household expenditures for trips, see 4(vii). Accordingly, car ownership levels will be affected by changes in travel budgets, travel costs, or number, length, and mode of trips.

Overall car ownership per household will increase (decrease) if, everything else being equal,

- household travel budgets increase faster (slower) than transport costs, i.e. the costs of owning and parking a car, car operating costs, and public transport fares,
- less (more) or shorter (longer) trips are made due to more condensed (dispersed) location of activities,
- road congestion decreases (increases) due to shifts in the location of activities.

Car ownership levels in particular zones will increase (decrease) if, everything else being equal,

- the proportion of high and medium income households in the zone increases (decreases),
- parking costs in the zone decrease (increase) due to changes in parking space demand or supply in the zone,
- car accessibility of the zone increases (decreases) due to changes in road congestion caused by shifts in the loaction of activities.

The above impacts become effective with the next execution of the transport submodel at the beginning of the subsequent simulation period.

5(iv) Land Use Effects on Congestion

Road congestion in the model is a function of car trips by household type and trip purpose, see equation 4.5, assigned to road links, see equations 4.10 and 4.11, and road link capacity, see equation 4.1. Accordingly, each change of land use resulting in a change of trip pattern will also affect the distribution of congestion in the road network.

In particular, road congestion will globally and locally increase (decrease) if, everything else being equal,

- household travel budgets increase faster (slower) than transport costs resulting in higher (lower) car ownership levels,
- activities shift to zones with good (poor) car accessibility resulting in more (less) and longer (shorter) car trips being made,
- more (less) and longer (shorter) car trips are made due to more dispersed (condensed) development.

The above impacts become effective with the next execution of the transport submodel at the beginning of the subsequent simulation period.

5(v) Land Use Effects on Transport Supply

Transport supply, i.e. roads, public transport lines, levels of service, and fares are user-specified, i.e. exogenous to the model and thus not endogenously influenced by changes of land use.

This does not preclude that the user in anticipation of land use changes specifies improvements of the transport system over time, see 7(viii).

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5(vi) Land Use Effects on Transport Costs

Transport unit costs, i.e. the costs of owning a car, car operating costs, and public transport fares are exogenous and are not affected by changes in land use.

However, average trip costs depend on trip rates, destination and mode choice, road congestion and parking costs and such are endogenous.

Each change in land use will result in a different equilibrium of car ownership, trip rates, destination and mode choice, road congestion, and trip utilities in the transport submodel and hence in different average trip costs.

In general, higher (lower) average trip costs can be expected if, everything else being equal,

- household travel budgets increase faster (slower) than transport unit costs,
- longer (shorter) trips are made due to more dispersed (condensed) location of activities.

These impacts become effective with the next execution of the transport submodel at the beginning of the subsequent simulation period.

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5(vii) Land Use Effects on Land Use

Changes in land use may affect other land use changes either instantaneously or with a one-period delay.

Within a simulation period, different land uses compete for limited resources, in particular for the limited supply of land and floorspace. With each new construction, land is utilized, and with each relocation of a firm or a move of a household floorspace is occupied. At the same time floorspace may be vacated by relocating firms or moving households. All these changes of land and floorspace supply are immediately recorded by the model. Thus each change in the location of activities affects the choice of all later location decisions during the period, see 3(v), 3(vii), 3(viii), and 3(xi).

In addition, new construction may result in demolition and high demand for office space may result in flats being converted into offices, see 3(xi). All workplaces or dwellings displaced in that way are replaced during the same simulation period by iterating the industrial and residential location submodels several times.

All other effects of land use changes on land use are delayed by one simulation period. They work through three channels:

- A changed distribution of activities will result in changed zonal attractiveness or neighbourhood quality indicators calculated at the beginning of the next simulation period.

- A changed distribution of activities will result in a different equilibrium of car ownership, trip rates, destination and mode choice, road congestion, and trip utilities in the transport submodel executed at the beginning of the next simulation period and thus in different zonal accessibility indicators, see equations 3.10 and 3.11, and migration utilities, see equation 3.11, for use in the next simulation period.

- The demand observed in different submarkets of the land and housing market during the simulation period will result in changed land prices and housing prices/rents for the next simulation period as calculated in the land price and rent adjustment submodels, see 3(vi) and 3(ix).

These three kinds of changes will result in new attractiveness indicators as calculated in equations 3.5, 3.6, 3.12, and 3.19. These indicators enter the spatial choice functions for migration and residential and industrial location such as 3.1-3.3, 3.4, 3.13-3.14, and 3.17-3.18.

5(viii) Transport Effects on Residential Location

A change in transport supply or costs will lead to a different equilibrium of car ownership, trip rates, destination and mode choice, road congestion, and trip utilities in the transport submodel executed at the beginning of each simulation period and thus to different zonal accessibility indices calculated as in equations 3.10 and 3.11. The accessibility indices determine, among other utility components, the allocation of new housing construction to vacant residential land as specified in equation 3.4.

In most general terms, a more dispersed (condensed) development of new housing will occur if, everything else being equal,

- transport costs increase slower (faster) than household travel budgets,
- accessibility differences between core and periphery decrease (increase) due to transport improvement (degradation).

A particular zone will attract a larger (smaller) share of the housing construction of the period if, everything else being equal, its accessibility increases (decreases) relative to that of all other zones due to local transport improvement (degradation).

Because of differences in profitability and locational requirements, the above tendencies may point into different directions for different dwelling types in one and the same simulation period.

For subsequent effects on the residential choice of households and on consequential changes of population, see 5(xi).

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5(ix/x) Transport Effects on Industrial Location

The mechanism of transport effects on industrial location is similar to the one described in the previous section for residential location.

A change in transport supply or costs will lead to a different equilibrium of car ownership, trip rates, destination and mode choice, road congestion, and trip utilities in the transport submodel executed at the beginning of each simulation period and thus to different zonal accessibility indices calculated as in equations 3.10 and 3.11. The accessibility indices determine, among other utility components, the spatial distribution of job redundancies and relocations, see equations 3.13 and 3.14, and the allocation of new jobs to vacant floorspace or in new buildings, see equations 3.17 and 3.18.

In most general terms, a more dispersed (condensed) spatial distribution of employment will result if, everything else being equal,

- transport costs increase slower (faster) than household travel budgets,
- accessibility differences between core and periphery decrease (increase) due to transport improvement (degradation).

A particular zone will lose a smaller (larger) share of employment by redundancies and relocations and will attract a larger (smaller) share of newly located jobs if, everything else being equal, its accessibility increases (decreases) relative to that of all other zones due to local transport improvement (degradation).

Because of differences in profitability and locational requirements, the above tendencies may point into different directions for different industries in one and the same simulation period.

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5(xi) Transport Effects on the Housing Market

Because intraregional migrations are modelled as search processes of households on the regional housing market, the housing market is the place where residential choice and changes of the spatial distribution of population are modelled.

Again, changes in transport supply or costs will lead to a different equilibrium of car ownership, trip rates, destination and mode choice, road congestion, and trip utilities in the transport submodel executed at the beginning of each simulation period and thus to different accessibility indices calculated as in equations 3.10 and 3.11. The accessibility indices determine, among other utility components, the attractiveness of a dwelling in a certain zone for a houshold and thus the decision to search for a dwelling or to accept an inspected dwelling, see, for instance, equations 3.1 and 3.3. Another transport-related measure used in the housing market simulation is the "migration utility" calculated as in equation 3.12. It determines the choice of a new housing zone during the housing search, see, for instance, equation 3.2.

In most general terms, the overall migration pattern will be centrifugal (centripetal) and result in a more dispersed (condensed) distribution of population if, everything else being equal,

- transport costs increase slower (faster) than household travel budgets,

- accessibility differences between core and periphery decrease (increase) due to transport improvement (degradation).

A particular zone will attract a larger (smaller) share of migration if, everything else being equal, its accessibility and migration utility increase (decrease) relative to those of all other zones due to local transport improvement (degradation).

Because of differences in incomes and locational preferences, the above tendencies may point into different directions for different household types in one and the same simulation period.

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5(xii) Transport Effects on the Labour Market

As the present model does not contain an explicit change-of-job submodel, see 3(xii), no effects of transport changes on labour market actor behaviour can be recorded.

However, work trip information produced in the transport submodel is used to predict unemployment at places of residence, see equation 3.21 in 3(xv). So if transport equilibrium work trips change due to changes in transport supply or costs, this will affect the unemployment predictions.

5(xiii) Transport Effects on Retail Location

Retail is treated like any other economic sector in the model, except that the accessibility of retail locations with respect to households is based on equilibrium shopping trips and is expressed in terms of retail sales per retail employee using equation 3.20 in 3(xiv).

This means that changes in transport supply or costs (including parking charges at the trip ends) leading to a redistribution of shopping trips between existing retail facilities will affect the attractiveness of zones for retail and thus the choice of location of relocating or new retail facilities.

In general, a more dispersed (condensed) spatial distribution of retail facilities will result if, everything else being equal,

- transport costs increase slower (faster) than household travel budgets,
- accessibility differences between core and periphery decrease (increase) due to transport improvement (degradation).

A particular zone will lose less (more) and attract more (less) retail jobs if, everything else being equal, its accessibility increases (decreases) relative to that of all other zones.

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5(xiv) Transport Effects on the Land Market

As the present model does not contain a separate submodel of the urban land market, changes of transport supply or costs can influence land prices only via the residential and industrial location submodels as described in 5(viii) and 5(ix/x).

In other words, if the accessibility and thus attractiveness of a land use category in a zone is increased by a change in transport supply or costs, this does not automatically affect its price. Only if as a consequence of such improvement the land is actually demanded for utilization, its price will go up, and even then with a one-period delay.

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5(xv) Transport Effects on Transport

The transport submodel is a simultaneous model of car ownership, trip rates, destination, mode, and route choice, road congestion, and trip utilities. That is, the transport equilibrium established at the beginning of each simulation period reflects all direct feedbacks between the above elements of the transport system. They are described in Section 4.

Second order feedbacks, i.e. consequential changes of car ownership, trip rates, etc. caused by land use changes which in turn were caused by changes of transport supply or costs, come into effect only with a one-period delay, at the beginning of the next simulation period. They are described as land use effects on transportation in 5(i) through 5(vi).

6 Data Requirements and Calibration

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DORTMUND

6(i) Base Year Data

The base year data of the model are, with few exceptions, readily available data from the 1968 and 1970 national censuses of housing, population, and employment as well as from other regularly published statistical tables.

The exceptions are:

a) For the housing market model, a cross-tabulation of households and dwellings by type (the "occupancy matrix") of each zone in the base year is required. In the Dortmund application, this data was assembled partly from tapes with household-by-household and dwelling-by-dwelling information of the 1968 census of housing and the 1970 census of population made available by the City of Dortmund, partly by using biproportional adjustment techniques for estimating the occupancy matrix from one-dimensional household and household distributions.

b) The land use pattern of the base year was taken from a land use inventory based on digitized aerial photographs prepared by the Ruhr Association of Cities (KVR).

c) Transport network data of the base year were assembled by extending an existing network coding for Dortmund to the entire study region using road maps and public transport timetables.

DORTMUND

6(ii) Special Surveys

No special surveys wered conducted for the Dortmund application.

6(iii) Data Requirements for Forecasts

Besides the base year data, the following three kinds of exogenous input are required for each simulation run:

a) Regional Forecasts

The development of the study region in relation to other regions is represented in the model by forecasts of employment by sector for the total region and of immigration into and out of the region. These forecasts may either be taken from an existing multiregional demoeconomic model of the state of Nordrhein-Westfalen or be exogenously prepared outside the model framework.

b) Model Parameters

For specifying the model functions, a relatively large number of model parameters have to be provided. There are nine groups of model parameters:

- demographic parameters,
- household parameters,
- housing parameters,
- employment parameters,
- workplace parameters,
- land use parameters,
- transport parameters,
- monetary parameters,
- preference parameters.

The first eight of these are expressed in physical-technical or monetary units or as rates or distributions. They can in general be calculated from published statistical tables for the past and with a certain degree of confidence be extrapolated into the future. The last group of parameters, the preference parameters, represent the behaviour of the model actors. They have to be calibrated, see 6(iv).

c) Policies

The model accepts localized and time-sequenced policies in the fields of land-use planning (zoning), housing construction, industrial development, public infrastructure, and transport. Except the land use plan, all policy inputs are optional. When present, policy inputs have precedence over endogenous allocations. Policies accepted by the model are discussed in more detail in 7(viii).

6(iv) Model Calibration

All behavioural equations of the model are multiattribute spatial choice functions of the multinomial logit type. In the calibration the parameters of these choice functions are determined such that the choice behaviour predicted by the model as closely as possible reproduces observed choice behaviour. The choice functions of the model include the following:

equations	submodel
3.1-3.3	migration
3.4	residential location
3.13,3.14,3.16-3.18	industrial location
4.5-4.8	transport

In these choice functions presently only the exponent multipliers or elasticities, denoted by Greek letters in the above equations, are calibrated statistically, while the endogenous utility terms in the exponents are still determined by less formal trial-and-error methods. Maximum likelihood is used as the criterion for estimating the elasticities.

Unfortunately, with few exceptions, only cross-sectional information of the base year is available for the calibration in the requisite disaggregate form. This is allright for the transport submodel, which refers to a particular day in the base year. The other three submodels refer to a time interval (a simulation period) and ideally require flow data or rates. Such data, however, largely do not exist or could be made available only with an unreasonable amount of effort, see 6(v). So for the estimation of most of the above equations cross-sectional spatial distributions of activities have to be interpreted as the outcome of past locations decisions, which clearly is far from being satisfactory.

Even without this restriction, the use of data of only one or two years for the calibration of a long-term forecasting model leaves the question of temporal stability of the parameters unanswered.

However, methods for calibrating multidimensional dynamic or quasi-dynamic recursive models with data of several points in time are virtually nonexistent. Therefore, in parallel to the work for ISGLUTI, efforts are undertaken to calibrate the model with similar cross-sectional data of the past census years 1950 and 1961 in order to learn more about the temporal evolution of the parameters. In addition, validation experiments have been conducted to evaluate the model's predictive performance during the period 1970 to 1980, see 7(x).

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6(v) Data Requirements for Calibration

If the model is calibrated, as it is presently done, predominantly from cross-sectional data, the base-year data used by the model anyway also serve as calibration data. The following data groups are used:

- the "occupancy matrix" for calibrating equations such as 3.1 and 3.3 of the migration submodel,
- the distribution of dwellings by type and zone for calibrating equation 3.4 of the residential location submodel,
- the distribution of employment by sector and zone for calibrating equations 3.13-3.14 and 3.16-3.18 of the industrial location submodel.

In addition, the following data not belonging to the data used in every simulation are required for calibrating the spatial interaction equations of the transport and migration submodels:

- the base-year work trip matrix by mode for calibrating equations 4.5-4.8 of the transport submodel,
- the matrix of intraregional migrations of the simulation period following the base year for calibrating equations such as 3.2 of the migration submodel.

In the Dortmund application, both kinds of data are not disaggregated by income group. Moreover, no trip tables are available for shopping, social and service, and school trips. For these trip purposes, only mean travel times and distances are available from a later transport study.

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6(vi) Computing Requirements

The model is presently operated on the University of Dortmund IBM/370-158 computer.

On this machine, the CPU time required for a 20-year forecast in 10 two-year periods for a 30-zone system is about one hour. When comparing this figure with computing times of other models, it should be taken into account that this old machine is about one order of magnitude slower than more recent and larger machines.

Using overlay techniques, the storage requirement of the simulation program is about 220 KBytes.

The computing requirements of the calibration programs are minimal.

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6(vii) Model Development

Work on the Dortmund region model started in 1977. Since that time, about 12 person-years have been spent on the model.

Of these, about 4 person-years have been used for model development and about 8 for model application. About 30 percent of the total work was done by students.

7 Applicability, Operationality, and Testing

Contents

DORTMUND

7(i) Spatial Scale of Study Area

The model was designed as the second level of a three-level model hierarchy consisting of

- a macroanalytic multiregional demoeconomic model of the state of Nordrhein-Westfalen,
- a mesoanalytic model of intraregional location and migration decisions in the Dortmund urban region,
- a microanalytic model of land use development in one or more urban districts of Dortmund.

Hence the spatial scale of the Dortmund region model is clearly urban. It could not be applied at a larger scale because it does not model interindustry linkages, the labour market, or employment-induced migration. It could be applied at a smaller scale to only a part of the present study area if external zones were introduced to represent the rest of the urban region, see 7(v). However, it could not be applied at the micro scale of the third model level because it fails to treat firms, buildings, sites, etc. as discrete entities.

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7(ii) Type of Study Area

The model was designed for an urban region. In a technical sense, it could be applied to a rural region, however with its focus on housing, land scarcity, and accessibility it would not address the issues presently most relevant for rural regions in the Federal Republic, such as economic decline, lack of infrastructure, and environmental conservation.

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7(iii) Study Areas of Model Applications

The only application of the model to date has been to the urban region of Dortmund.

Dortmund (pop. 610,000) is the centre of an urban region covering an area of about 16,00 square kilometres with a population of about 2.3 million and about 930,000 workplaces. Its economic structure is largely determined by two industries, coal mining and steel manufacturing, so Dortmund is presently severely affected by the worldwide decline of the steel industry.

The spatial structure of the Dortmund urban region is characterized by its being a part of the multicentred Ruhr region (pop. 5.4 million). So the study area includes, besides Dortmund, three major industrial centres, Bochum (pop. 400,000), Hagen (pop. 230,000), and Hamm (pop. 180,000). The regional public transport system consists of rail, tramway, and bus, but motorization plus major investments in road construction during the sixties and seventies have made intraregional transport heavily dependent on the private automobile.

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7(iv) Spatial Scale of Model Applications

The study area of the Dortmund application is subdivided into 30 geographical subdivisions or zones.

The 30 zones vary considerably in size. In the core of the region the zones are the 12 urban districts of Dortmund. They range in population between 40,000 and 60,000. At the periphery of the region the zones are municipalities. They vary in population between 15,000 (Holzwickede) and over 400,000 (Bochum). The whole study region has a population of about 2.3 million.

DORTMUND

7(v) Closure of the Spatial System

The relationships between the study region and its spatial environment are represented by the top level of the three-level model hierarchy, the Nordrhein-Westfalen model.

In the original model design it was intended to implement two-way interactions between both model levels. However, to date only top-down information is transferred from the Nordrhein-Westfalen model to the Dortmund region model. Such information consists of forecasts of employment by sector for the whole region and of immigration into and outmigration out of the region by age, sex, and nationality for each simulation period.

In the transport submodel, the 30 zones of the Dortmund urban region are presently treated as a closed system. The rationale for this is that substantial proportions of trips entering or leaving the study area are found only in the peripheral zones. As a consequence, the accessibility of the peripheral zones calculated in the model may be marginally lower than in reality. This is one of the reasons why the peripheral zones of the study region are labelled "external zones" in the ISGLUTI study.

For future work it is planned to use the regions of the Nordrhein-Westfalen model as external zones.

7(vi) Model Dynamics

For each two-year simulation period and for each zone, the model produces forecasts of the following stock variables:

- population ($20 \times 2 \times 2$),
- labour force/unemployment (4/4),
- households ($5 \times 4 \times 3 \times 2$ and 30),
- dwellings ($5 \times 4 \times 3 \times 2$ and 30),
- households $\times$ dwellings (30×30),
- jobs/workplaces (40/40),
- land use (30),

where the numbers in brackets indicate the disaggregation following the cross-classification scheme listed in section 2(iii).

In addition, the model produces for each simulation period the following spatial interactions between zones:

- weekday morning peak-period trips by purpose, income group, and mode ($4 \times 4 \times 3$),
- migrations of households by household type group/persons by age group (4/4),

where again the numbers in brackets indicate the level of disaggregation.

Besides the stock variables listed above, the model produces for each simulation period and zones indicators such as:

- housing prices or rents (30),
- land prices (10),
- accessibilities (4×10),
- utilities, land use (40×10, 12×10),
- utilities, dwellings (30×31),
- etc.

where the number in brackets denote the number of indicators calculated for each zone.

All the above model variables are endogenous, i.e. are the result of functional model relationships most of which are nonlinear. So potentially all these variables change their values over time, although some of them may prove to be more or less time-invariant.

Also all model parameters specified by the user are time-dependent, except where their changes over time seem to be so slow as to warrant keeping them fixed. For instance, age-specific, regional fertility rates are projected for each simulation period following exogenous forecasts, while age-specific survival rates are known to be almost stable over time and therefore are not changed during the simulation.

One unfortunate exception are the elasticity parameters of the behavioural model equations calibrated from cross-sectional data as listed in 6(iv). Despite the reservations expressed there, they have to be kept fixed during the simulation due to lack of information on their temporal development.

As all other model input and output, also the policies entered by the user have a time dimension. Entries in the zoning plan either carry an explicit time lable or specify an equal annual rate of land to be released for development. Similarly, housing, industrial location, infrastructure, and transport projects are either initiated in a certain year or annually and become effective after an appropriate time delay.

7(vii) Decline and Rapid Growth

The model should consistently handle any combination of total regional employment and regional immigration and outmigration forecasts.

However, due to the hierarchical model structure, there is no feedback between employment and immigration and outmigration on this model level, because this is handled on the top model level, in the Nordrhein-Westfalen model. For instance, if large-scale net immigration is specified without a corresponding provision of jobs, mass unemployment will occur with consequential effects on household incomes, car ownership, and housing construction. Conversely, if jobs are increased rapidly without the corresponding net immigration, the labour participation rate and thus household incomes, car ownership, and housing construction may arrive at unreasonable levels. However, in that case housing construction may be restricted by lack of land.

In the observation period of the Dortmund application, 1970 to 1980, a short phase of growth of employment and population was followed by a longer and still ongoing period of economic and demographic decline.

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7(viii) Policies

As the Dortmund model is a simulation model, policies to be tested have to be compared with a do-nothing alternative or with another policy. The model does not contain a formalized evaluation procedure.

The policies that can be tested with the model may be local or global. Local policies refer to a certain zone or to a particular network link. Presently the following local policies are accepted by the model:

a) Land Use

The release of land for development is controlled in the model by the zoning plan, see 3(iv). The zoning plan specifies any number of land use changes defined by

- zone,
- year(s),
- old land use category,
- new land use category,
- area (hectares),
- maximum density.

Land use changes in the zoning plan become effective only when land of the "new" land use category is actually utilized for residential or industrial construction or for public facilities, see below. Where the "old" land use category is built-up land, demolition occurs. If no zoning plan is specified or if the land supply of the zoning plan is exhausted, no new construction is possible except where additional land can be cleared by demolition, see 3(xi).

b) Housing

The user may specify any number of housing projects defined by

- zone,
- year(s),
- dwelling types(s),

- number of dwellings,
- project type,

where "project type" may be demolition, upgrading, or new construction. New housing construction projects started in one period are released to the housing market only in the subsequent period. User-specified housing projects, if present, have precedence over endogenous housing construction, i.e. reduce or increase the demand for private housing construction.

c) Workplaces

The user may specify any number of projects resulting in a change of employment defined by

- zone,
- year(s),
- sector(s),
- number of workplaces,
- project type,

where "project type" may be the closure of a plant, with or without clearance of the property, or new construction. User-specified employment changes have precedence over endogenous changes produced by the industrial location submodel, i.e. reduce or increase the demand for new workplaces.

d) Public Facilities

The user may specify any number of public facility projects defined by

- zone,
- year(s),
- facility type,
- number of units,
- project type,

where "project type" may be closure or new construction. This is the only way to change the stock of public facilities in the model, i.e. there is no endogenous public facilities submodel.

e) Transport

The user may specify for both transport networks any number of network changes defined by

- link,
- year,
- parameters,
- project type,

where "parameters" are link parameters such as link type, length, travel time/speed, lines, and level of service, and "project type" may be deletion, change, or new construction. Using this information, the two transport networks are updated at the beginning of each simulation period. A network link may be changed more than once during a simulation.

Global policies refer to the study region as a whole. They represent changes of the regional forecasts and model parameters described in 6(iii):

f) Regional Forecasts

The user may specify any reasonable combination of employment and immigration/outmigration forecasts for the region subject to the reservations expressed in 7(vii). As global demoeconomic development of the region is assumed to be exogenously determined, variations of the regional forecasts do not represent policies in the strict sense, but rather experimental scenarios.

g) Model Parameters

The trajectories of all exogenous parameters listed in 6(iii) may be experimentally varied to test the response of the model to such variation. A variation of a parameter may represent either a policy or a scenario: If the parameter values are at the disposal of local or regional authorities, the change may represent a realistic policy, otherwise it represents a sensitivity test or scenario.

Parameter changes representing real policies in the model are, for instance, changes of

- global zoning regulations,
- housing allowances/subsidies,
- public transport fares,
- parking charges.

Parameter changes representing sensitivity tests or scenarios are, for instance, changes of the trajectories of

- fertility rates,
- household formation rates,
- incomes, housing or travel budgets,
- costs of car ownership, of petrol,
- costs of housing construction,
- space requirements of industry.

A special kind of global policies (or scenarios) consists in systematically manipulating zonal or network data in order to test global changes of the spatial system, e.g. to artificially shift population or employment between zones or to introduce different speeds or levels of service on all network links of a certain kind.

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7(ix) Use in Policy Formulation

The Dortmund model was designed as a research model and has not yet been used for a client.

However, several studies have been performed in which current policy issues of the Dortmund region were addressed. One study investigated the suburbanization effects of different szenarios of regional economic and demographic development. Another study modelled the effects of large-scale reductions in employment in the steel manufacturing industry on the local housing market.

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7(x) Model Validation

The model results of the simulations starting in 1970 have been compared with actual data of regional development during the period 1970 to 1980.

Population forecasts by zones and by aggregates of zones (subregions) have been excellent, with the r^2-statistic ranging between 0.9997 and 0.9965 for different simulation periods. This means that after five simulation periods, or ten years, only 5 out of 30 zones had predictions errors of more than 10 percent and none over 15 percent, while 17 out of 30 zones were predicted with an error of less than 5 percent.

Nearly equally good results were obtained when comparing migration flows between zones with observed migration flows with the r^2-statistic ranging between 0,9810 and 0.9572 for different simulation periods. However, prediction performance was less satisfactory when only small migration flows were compared.

No similar analysis was possible for daily trips between zones, because no trip tables except the base-year work trip table used for the calibration were available. In the calibration, an r^2 of 0.9977 for all trips and of 0.9986 for travel time frequencies were obtained.

Model validation for other variables is constrained by the fact that there has not been another census of housing, population, and employment in the Federal Republic since 1970. In particular housing and employment figures from other sources are either incomplete or use a different classification or are not spatially disaggregated in the way required by the model. So model results could be compared with observed data only for aggregates of variables and for counties instead of zones.

Such aggregate analyses were made, among others, for housing, employment, and unemployment rates. On this level of aggregation, correspondence between model predictions and reality was found to be good. In particular, the model well reproduced the temporal characteristics of spatial processes in the region with respect to slope and relative position and the sequence of peaks and bends of the trajectories over time.

More disaggregate, but partial, analyses could be made for individual counties or for subsets of zones. Sectoral forecasts of employment for the counties of Dortmund, Bochum, and Hamm proved to come close to reality except for mining and energy, where major state interventions could not be anticipated by the model. An analysis of housing construction by period for selected zones, where such data were available, showed still substantial prediction errors resulting in r^2-statistics in the range of 0.6. More data collection from local authorities will be required to substantiate and complement this kind of results to bring them into a communicable format.

7(xi) Sensitivity Tests

As the model is a simulation model, each simulation run with a different set of inputs is in a way a sensitivity test. In this loose sense, numerous sensitivity tests have been performed.

However, to date no systematic sensitivity tests have been performed, in which one model parameter at a time is systematically varied and the results recorded in order to study the response of the model to changes of that parameter where everything else is being kept equal.

7(xii) Programming Language

All computer programs are written in Fortran IV as accepted by the IBM Fortran H Extended Compiler.

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7(xiii) <u>Type of Computer</u>

The model was developed on the University of Dortmund IBM/370-158 computer, see 6(vi). The housing market simulation part of it was also run on the Decimal Equipment VAX 11/780 computer at the International Institute for Applied Systems Analysis in Laxenburg.

If the model were to be transferred to another computer, transferring the computer programs themselves would probably be straightforward, but setting up the quite elaborate system of input, output, supportive, or backup files, some permanent, some temporary, required for the model might prove to be difficult.

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7(xiv) Model Transferability

Although the model was designed as a coherent, easy-to-use, interactive program package, it may not be easy to transfer it to other users or data sets.

One reason for this is related to its size and the number of its parameters and functional relationships. Without a detailed knowledge of its internal working, calibrating and using it may be very difficult. The present model documentation is insufficient to provide the necessary information.

Another reason are the relatively large data requirements of the model. In particular the required cross-classification of households and dwellings (the "occupancy matrix") may be unobtainable in most other study areas.

8 Model Output, Presentation, and Policy Evaluation

Contents

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8(i) Output

During a simulation run no user-readable output is produced except a simulation protocol on the terminal. All information generated during the simulation is preserved on computer files for later analysis, comparison, and printout.

The printout program is an interactive procedure for selecting from several output options. Presently the following options are available:

1 Population and Employment: Population by age group and nationality and employment by sector in each zone.

2 Housing Occupancy: The "occupancy matrix" and the corresponding matrix of housing satisfaction of each zone.

3 Land Attractiveness: The attractiveness indicators of each land use category in each zone for industrial location by sector and residential location by dwelling type.

4 Trip Attributes and Trips: Travel times, travel distances, travel costs, trip utilities, and trips by purpose, income group, and mode--in different levels of aggregation.

5 Household Development: For each household type in each zone, the number of households, household income, and housing budgets, and number of dissolved and new households, inmigrations and outmigrations, moves, redundancies and new jobs.

6 Housing Development: For each dwelling type in each zone, the number of dwellings, floorspace and rent, and number of upgradings, demolitions, conversions, and new constructions.

7 Migrations: Migration utilities and migrations of households by household type group and of persons by age group.

8 Maps: A selection of lineprinter maps showing the spatial distribution of various indicators such as accessibilities, housing satisfaction and other attractiveness indicators, or of rates

of change of aggregate variables such as population, households, dwellings, or employment.

9 Zonal Summaries: A combination of graphical output produced on the lineprinter and of tables containing trajectories of various summary indicators for zones, see 8(ii).

10 Regional Summary: A combination of graphical output produced on the lineprinter and of tables containing trajectories of summary indicators for the whole region, see 8(ii).

Print options 1 through 7 may be produced for each point in time or period, respectively, or for a five-period interval or for the whole simulation only. Where appropriate, besides zonal results also aggregate results for any desired aggregates of zones (e.g. core, suburban, periphery) and for the total region are presented. Maps are produced only for the base year and the last year of the simulation. The zonal and regional summaries always cover the entire simulation.

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8(ii) Summary Figures

Because of the large volume of output produced by print options 1 though 7, normally only the two summary options 9 and 10 are selected.

a) Zonal Summaries

Print option 9 produces lineprinter graphs of one variable plotted vs. time or of two variables plotted vs. each other where each plotted point represents a zone at a point in time. Besides zonal trajectories, also aggregate trajectories for up to four subregions (any desired aggregates of zones) and for the total region are presented. Each graph is accompanied by one or two tables containing the numbers plotted.

Presently the following zonal indicators can be plotted:

- population,
- percent foreign population,
- percent population over 60 years,
- employment,
- employment, public service,
- new jobs minus redundancies,
- unemployment rate,
- labour participation rate,
- age vs. household income,
- housing satisfaction vs. rent,
- car ownership,
- percent public transport use,
- travel time,
- travel distance,
- travel cost,
- trips,
- net migration by income group,
- land attractiveness by land use type,
- dwellings,
- percent new dwellings,
- percent vacant land by land use type,
- land price by land use type.

The print program is organized modularly so that it is easy to remove indicators or to add new ones.

b) Regional Summary

Print option 10 is similar to print option 9 except that it plots indicators for the whole study region. This makes it possible to plot up to 40 variables at a time, for instance,

- population by age group,
- employment by sector,
- households by household type,
- dwellings by dwelling type,
- subtenants by household type,
- vacant dwellings by dwelling type,
- etc.

In addition, aggregates of the above disaggregations can be plotted in analogy to the subregions of the zonal summaries program. Also the regional summary program is organized such that removal and addition of indicators are easy.

8(iii) Interaction with the User

All programs for calibration, input preparation, simulation, and output processing are interactive.

A simulation run can be completely specified, started, and monitored from a terminal. During the simulation, a simulation protocol showing the progress of the simulation is displayed at the terminal. The user may at any point in time interrupt the simulation, inspect intermediate results and either resume the simulation or repeat any desired number of simulation periods with different parameters or policies.

However, due to the insufficient hardware available and the resulting long computing times, see 6(vi), the simulations are normally run overnight in the batch mode without monitoring by the user.

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8(iv) Presentational Aspects

There exists an interface between the printout program described in 8(i) and the DISSPLA graphics package. This interface permits to draw maps and graphs of print options 8 through 10 on a drum plotter instead of the lineprinter, but it is rarely used.