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# A MULTI-LEVEL DYNAMIC SIMULATION MODEL OF INTER-REGIONAL AND INTRA-REGIONAL MIGRATION

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A B S T R A C T

In this project the relationships between inter-regional and intra-regional migration, and between locational choice, mobility, and land use in urban regions are investigated with the help of a dynamic simulation model of regional development. The model is designed to simulate location decisions of industry, residential developers, and households, the resulting migration and commuting patterns, the land use development, and the impacts of public planning instruments in the fields of land use planning, public infrastructure, and public housing in the urban region of Dortmund. For this purpose a simulation model organised in three spatial levels connected by feedback loops is being developed and tested. The paper reports on the structure of the model and on the modelling techniques applied.

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## 1. The Problem

During the last thirty years, West Germany like many other countries went through a period of rapid urbanisation which resulted in the growth of a few major urbanised centers at the expense of the rest of the country. In recent years, however, the urbanisation process seems to be changing its pattern. Most large cities experience a decline of population, while the communities at the periphery of urban regions continue to grow at a fast rate. There are mainly two reasons for the decreasing attractivity of the urban core: The agglomeration of factories, traffic arteries, and residential areas in the crowded central cities causes a steady deterioration of the physical and social quality of urban life. At the same time the housing preferences of the population change towards suburban living at a quiet place with clean air and easy access to outdoor recreation. Consequently, especially younger households with higher incomes leave the cities and move to the less urbanised periphery of the urban regions.

The consequences of this exodus from the urban centres - loss of tax income, mono-functionality of the city centre, increasing spatial segregation of age and income groups, and urban sprawl at the periphery - make this a serious problem for many cities. Location and migration theory, at least in the Federal Republic, so far have failed to provide public decision makers with enough insight into the causes of intra-regional migration to enable them to plan for or influence this process.

Because of the growing interest of many cities in the problem of suburbanisation, during the last few years first major studies on intra-regional mobility have been conducted. In the years 1975 to 1977 the Federal Ministry of Regional Planning, Building and Urban Development sponsored housing market studies in ten major urban regions. Concurrently, similar studies for the cities of Bochum and Düsseldorf were supported by the Ministry of the Interior of the state of Nordrhein-Westfalen. These and other studies contain a wealth of empirical material on migration motives and location preferences of households. However, only in very few of them it was attempted to integrate the details of information into a coherent model of intra-regional migration.

To develop such a model is the main objective of this project. Because of that, no empirical data are collected, but the project builds upon the findings of existing studies in order to construct a model of intra-regional migration consistent with the available data.

The model building proceeds from the hypothesis that, in contrast to older theories of urban development, in urban regions with modern transport technology there is no simple sequence of spatial allocation from basic industry to residences and from residences to service industry. Instead, the location decisions of various groups of investors and users are determined by group-specific limitations of information and choice and by multi-dimensional preference systems in which factors of spatial access play a still important, but gradually decreasing role. In the long run, this leads to a spatial distribution of households and work places which is suboptimal with respect to transport cost, especially for certain types of users such as commuters, students, or house wives.

The project is therefore aimed at the investigation of the relationships between locational choice, mobility, and land use in urban regions. For this purpose a spatially disaggregated dynamic simulation model of regional development is being designed to simulate

- location decisions of industry, residential developers, and households,
- the resulting migration and commuting patterns,
- the land use development, and

- the impacts of public planning instruments in the fields of land use planning, public infrastructure, and public housing

in a concrete regional context. It was decided to use the urban region of Dortmund as a study region, including Dortmund and 19 neighbouring communities with a total population of 2.4 million. The purpose of the model is to simulate different planning strategies for the Dortmund region and make their outcomes comparable. To facilitate the application of the model, in the model design much emphasis is placed on aspects of man-machine communication.

## 2. The Model

The model being designed is a dynamic simulation model organised in three spatial levels connected by feedback loops. The model consists of

(1) a macroanalytic model of the economic and demographic development of 34 labour market regions in Nordrhein-Westfalen ("Regional Model"),

(2) a microanalytic model of intra-regional location and migration decisions in the 29 zones of the urban region of Dortmund ("Zonal Model"),

(3) a microanalytic model of land use development in one or more districts of Dortmund ("District Model").

The "Regional Model" constitutes the first level of the three-level model hierarchy. Its purpose is to forecast the labour demand in the labour market region of Dortmund and of the population in the residential communities belonging to it. These forecasts serve as the framework for the simulation of intra-regional location and migration decisions of industry, residential developers, and households in the subsequent Zonal Model.

The Regional Model was designed as a multi-region SYSTEM DYNAMICS model. In order to be consistent with existing population and employment projections for Nordrhein-Westfalen, the state has been exhaustively subdivided into 34 labour market regions one of which is Dortmund.

The competition between the Dortmund region and all other regions results in inter-regional migration of labour and capital subject to perceived attractivity differences between the regions. Except that, the Regional Model consists of 34 identical submodels, one for each region, each containing a population, economy, housing, and infrastructure sector (Fig. 1). The consideration of housing and infrastructure as separate model sectors reflects the growing importance of the regional housing and infrastructure supply for migration decisions of households and enterprises.

Starting point of the simulation in the Regional Model is the biometric population projection by age, sex, and nationality. From that the "internal" labour supply of the region by age, sex, nationality, and qualification level is derived. The subsequent household projection distinguishes households by size and income. The distribution of households by size and income determines the regional demand for housing and household-serving infrastructure in the region.

Economic projections are made for 40 industrial sectors. The projections are based on a combination of shift analysis and regional attractivity analysis. The shift analysis warrants the consistency of the projected development in each region with the global projections for Nordrhein-Westfalen. The disadvantage of the unstable location component caused by the high disaggregation is compensated by smoothing it by means of a first-order delay. The actual size of the location component is determined by the regional attractivity as viewed by the enterprises.

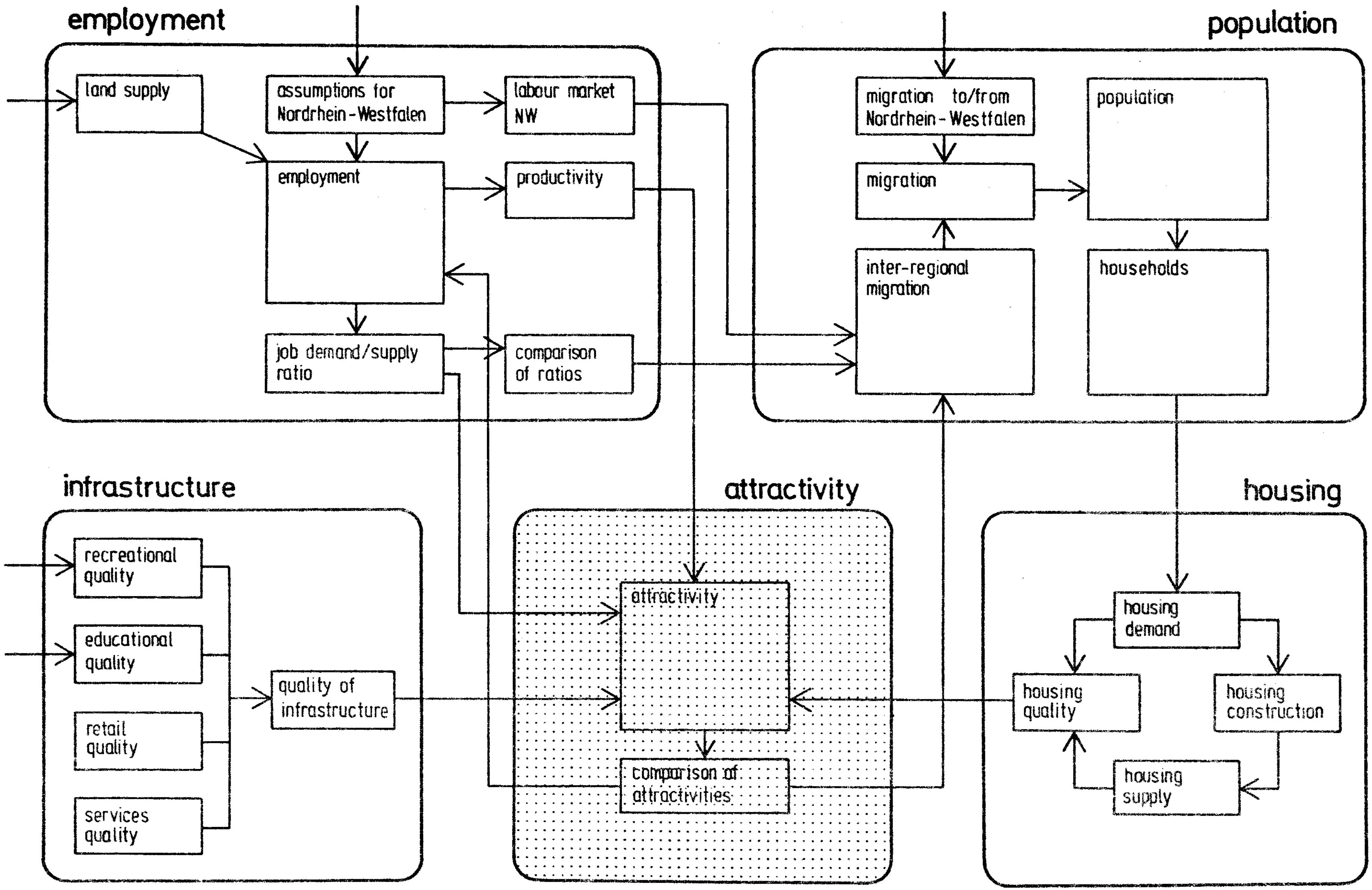


Fig. 1 The Regional Model

The number of jobs derived from the economic projections, i.e. the demand for labour in each industrial sector in each region is confronted with the "internal" labour supply. The labour supply/demand ratio characterises the labour market conditions in each region. It is supposed that, subject to overall labour market conditions in all regions, the labour supply/demand ratio affects inmigration and outmigration of a region in different ways: Especially at times of high overall unemployment rates inter-regional migration will be caused predominantly by the availability of jobs. Migration into or out of a region further depends on the attractivity of the region as a place to live and work as seen by the households.

A central role in the Regional Model plays the concept of attractivity. The attractivity of a region is expressed as a weighted aggregate of component attributes of the region as seen and evaluated by certain types of users. The attractivity model of households is mostly affected by regional wages and the supply of housing and household-serving infrastructure. In the model a regional productivity index is taken as a substitute variable for the regional wage level. The attractivity of the regional housing supply is measured by size and quality relative to the housing demand of households by family size and income. The quality of household-serving infrastructure is measured by the availability of different kinds of public and private services in the fields of health care, education, retail, local services, entertainment, and recreation. The attractivity model of industry considers factors such as the labour supply of the region, the availability of financial aids, and the quality of the housing supply and of the business-serving infrastructure of the region. Among the business-serving infrastructure the availability of vacant land for industrial development and access to long-distance traffic routes are the most important kinds.

The second level of the model hierarchy is the "Zonal Model". In it intra-regional location decisions of enterprises, developers, and households, and the migration and commuting patterns resulting from them are modelled. The simulation in the Zonal Model is based on the results of the Regional Model. The study area of the Zonal Model is the labour market region of Dortmund including Dortmund itself with its ten urban districts plus ten neighbouring communities, as well as nine residential communities outside the labour market region. Thus the study area is divided into 29 zones.

Like the Regional Model, the Zonal Model comprises the sectors of economy, population, housing, and infrastructure, but it also includes land use and traffic (Fig. 2). The population sector figures in the model mainly in the form of households classified by nationality, size, age, and income. Correspondingly, housing is classified by type of building, ownership, condition, age, and size. As in the Regional Model, the concept of attractivity is central to the Zonal Model. Attractivity in the Zonal Model can be attributed to many things. It may be the attractivity of a site as seen by the industrial manager or the residential developer, or it may be the attractivity of an apartment or a house as seen by a household, i.e. an aggregate of size, quality, and location in relation to price. In any case, the attractivity strongly influences all decisions of the model actors.

Unlike in the Regional Model, the computational sequence in the Zonal Model does not follow the above model sectors. Instead, during a simulation period the Zonal Model passes through a sequence of four submodels:

In the first submodel called the "updating" submodel all time-dependent changes of households and dwellings which result from biological, technological, or long-term socio-economic trends are computed. For households this includes demographic changes of household status in the life cycle

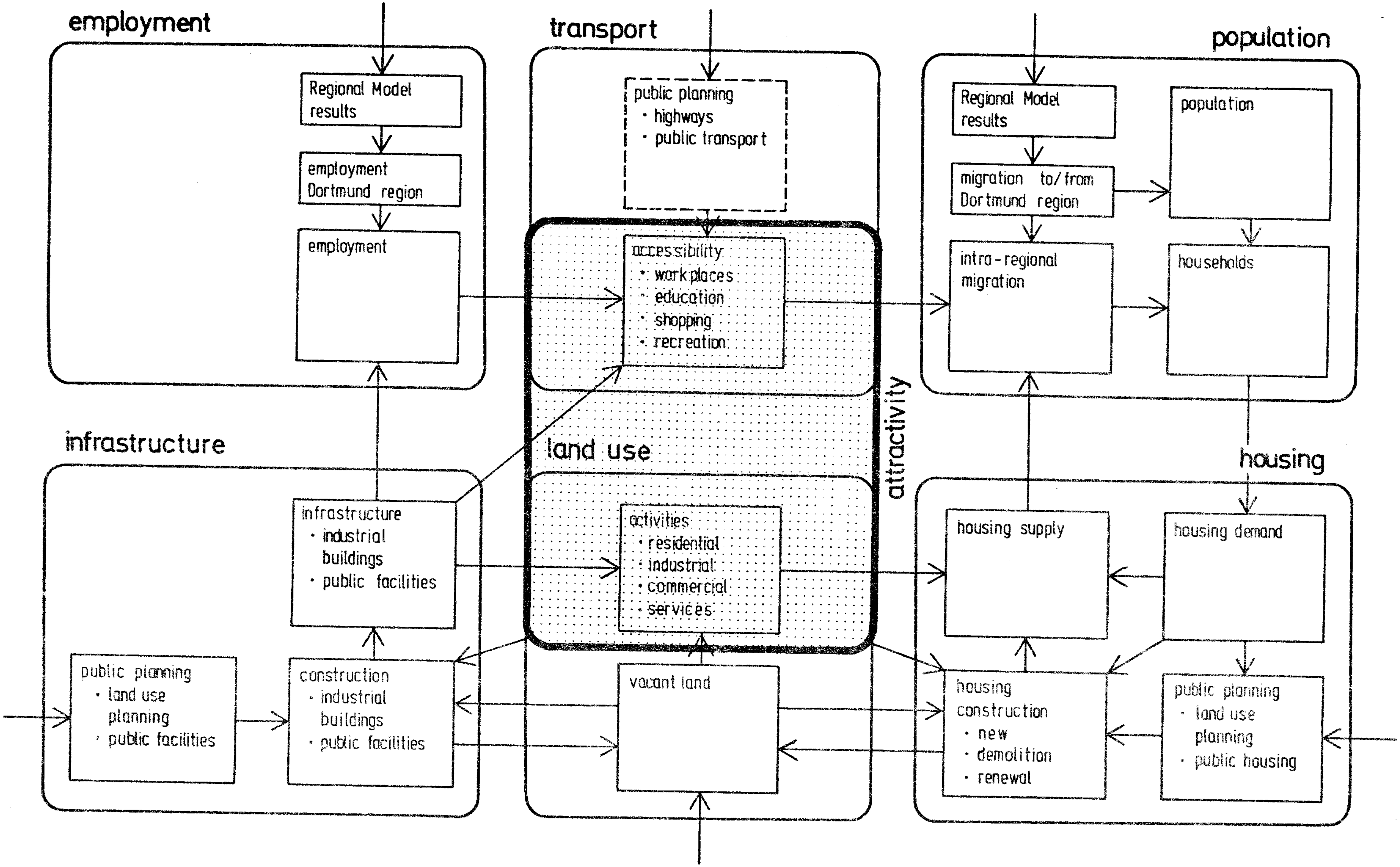


Fig. 2 The Zonal Model

of a household such as birth, aging, death, marriage, and divorce, and all new or disappearing households resulting from these changes. On the housing side it includes aging of the housing stock and certain types of renewal and demolition processes. This part of the submodel is programmed as a Markov model with dynamic transition rates between household and housing types. In addition, the time-dependent changes of all prices which are relevant to the model are calculated, such as the cost of living index, travel costs, construction costs, rents, and land prices.

In the second, the "public planning" submodel, public planning programs introduced by the user are executed. The model accepts the introduction of time-sequenced and localized programs in the fields of zoning, infrastructure, housing construction, and urban renewal. The model checks each program for feasibility and stores it for later execution. After an appropriate time delay the program is actually executed. With housing and urban renewal programs, the changes of rents and land prices resulting from them are also modelled in this submodel.

In the third, the "migration" submodel, intra-regional migration decisions are simulated. Migration is defined as a household's change of location encompassing a change of residence. Consequently, the intra-regional migration model is in fact a housing market model. It simulates the behaviour of households which give up their apartment or house and look for a new one, wheather by moving into or out of the region, or by moving from one place within the region to another. Besides, there are newly founded households looking for a dwelling, or households which unvoluntary have to vacate their dwellings for various reasons. Because of the linkage between housing supply and housing demand by vacant dwellings being put on the market with each move the housing market in a way represents a complicated circular exchange system. Modelling this circular exchange system requires the analysis and quantification of the motives which make a household of a certain type in a certain housing situation decide to move. It is assumed that a household having the intention to move actually does only move if it finds a dwelling that gives it significantly more satisfaction than its present one. The satisfaction of households with their housing situation is measured in the model by multi-dimensional preference structures, one for each household type, by which the attractivity of dwellings is assessed in terms of size, quality, location, rent or price, as seen by each household type. The housing market model was programmed as a Monte Carlo simulation model with dynamic event probabilities.

The fourth submodel is the "private construction" submodel. In it location decisions of the great number of private developers are modelled, i.e. of the enterprises which erect new industrial or commercial buildings, and of the residential developers which build apartments and houses for sale or for rent or for their own use. The predominant attractivity criteria for developers are land availability and suitability for the intended use, and location, and price. The volume of private construction is determined by the Regional Model, however the volume of housing construction also dynamically responds to the housing demand observed on the housing market. Housing demand and new housing construction may lead to further changes of rents and land prices.

The third level of the three-level model hierarchy is established by the "District Model". At this level the land use development allocated in the Zonal Model to individual zones is further distributed to individual tracts within one ore more zones. Any zone or combination of zones could be included in the District Model, but data collection for the District Model will be limited to the ten urban districts of Dortmund.

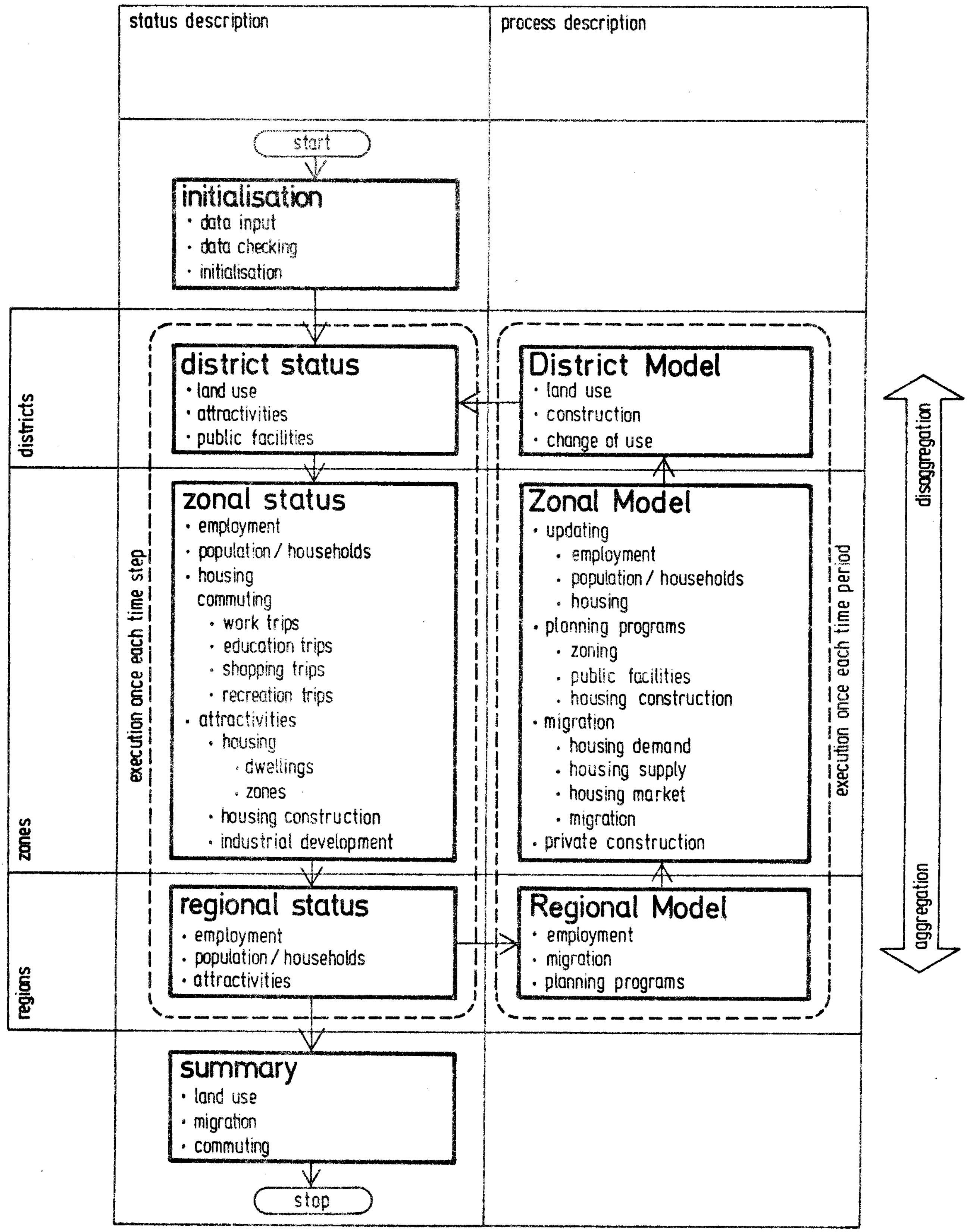


Fig. 3 Model structure: space and time

The dynamic feedback between the three levels of the model is established by superimposing them with the recursive temporal structure of the model. Fig. 3 illustrates this superposition. The horizontal layers of the diagram represent the spatial levels of the model, upside down. The vertical columns of the diagram represent the two basic modes of operation of the model: The status description parts of the model refer to points in time, i.e. the beginning and end of each simulation period. The process description parts refer to the time intervalls between those points, i.e. the simulation periods. Each element of the simulation model can be located, by line and column, in this matrix. The pointers in the diagram indicate sequence of operation as well as information flows.

The simulation begins at the symbol "start" and first passes through an initialisation block. Then the recursive cycle of the model is entered. The first cycle begins with the status description of the base year, first at the lowest of the spatial levels, then, by stepwise aggregation, at the zonal and regional levels. At the regional level the first simulation period begins, i.e. the description of change processes between the base year and time t = 1. In the diagram, this means to step from the left to the right column. The Regional Model is executed first of the process description parts. Its results are the input to the Zonal Model, and so forth, until eventually the results have been disaggregated down to the detail level of the District Model. That closes the first simulation period. The model again changes to the left column of the diagram and starts, with different state values, the next status description. This cycle of aggregation and disaggregation is iterated for each simulation period, until the last time interval has been simulated. In this case the model proceeds through a final report phase and closes down at the symbol "stop".

## 3. Modelling Techniques

The simulation model developed in this project combines four different simulation techniques:

- dynamic simulation following the SYSTEM DYNAMICS approach,
- recursive simulation, as it is used in many land use and transportation models,
- probabilistic simulation in the form of Markov processes,
- stochastic Monte Carlo simulation.

Thus the model has many direct or indirect predecessors. In particular, elements of two earlier simulation models developed by one of the authors at Battelle-Institut Frankfurt have been incorporated in the Zonal Model. However, the present model differs from other models in a number of significant features.

First of all, there is the three-level spatial model hierarchy. Only by this multi-level structure of the model the coherent modelling of spatial phenomena from state level down to small tracts within an urban district becomes possible at a still reasonable level of model complexity. Thus it can, for the first time, be attempted to study the interrelationships between long-distance migration, local migration, and commuting in one single model.

A second significant feature of the simulation model is the linking of the land use and migration submodels by a model of the regional housing market. Existing land use models usually simulate location decisions of residential developers, but ignore the interdependency between housing supply and housing demand represented by the consumers of dwellings on the housing market. Existing housing market models usually focus on the housing demand with the housing supply as given, or they assume total elasticity of the supply side and thus disregard the important restriction of land availability. In the model developed in this project the causal chains between land use development and population mobility and vice versa are traced explicitly in the submodels of public and private residential construction and of the housing market.

Finally, there is the stochastic model of the regional housing market itself. Like no other modelling technique, the Monte Carlo technique as it is used here makes it possible simultaneously to take into account objective and subjective, economic and noneconomic determinants of the individual decision situation of migrant and nonmigrant households, as well as their limited information and choice of the dwellings offered on the market. The model is therefore well suited to reflect psychological hypotheses about human behaviour in successful or unsuccessful search processes. In addition, the model explicitly addresses the question most relevant to this project, namely the decision of households between long-distance commuting and short-distance migration by considering the work place in the household's moving decision. Moreover, the modelling technique solves the problem of simulating circular exchange processes on the housing market in a straightforward and natural manner.

Other features of the model which might be of methodological interest, such as the spatial disaggregation of the SYSTEM DYNAMICS technique, the specific use of the shift analysis forecasting technique, and the integration of the labour market, housing, and infrastructure submodels in the Regional Model cannot be treated in detail in this paper. The intensive efforts of the project team to achieve an easy, comprehensible, and safe way of communication between the model and the model user can also only be mentioned here.

## 4. Project Status and Future Work

The work of the project started in the second half of 1976 with the conceptualisation of the model and the collection of base year data for the first two spatial levels of the model. The current work focusses on the actual construction of the model. By now, first versions of the Regional Model and the Zonal Model have been completed as interactive computer programs and are being tested with preliminary data.

It is planned that by the end of 1978 the model will be operational as a tested and documented computer program. By that time it should also have been possible to demonstrate work with the model by a number of contrasting alternatives for the strategic planning of Dortmund. This includes a first preliminary calibration of the model with migration data of Nordrhein-Westfalen and of Dortmund.

For the time after 1978 a follow-up project addressing the same subject matter in a more comprehensive framework is being proposed. In the future project the relationships between economic change (sectoral, technological change, etc.) and the spatial development of an urban region are to be studied with the help of the model described in this paper. Obviously, the current model will have to be modified in some of its parts to reflect the larger subject. In addition, it is planned to calibrate the model more thoroughly with data on migration motives and location preferences of households from the empirical studies mentioned at the beginning.

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2. K. Lüthje, J. de Wendt: Bestimmung wanderungsrelevanter Haushaltstypen (December 1976)

3. Kleinräumige Standortwahl und intraregionale Mobilität: Arbeitsplan (January 1977)

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