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THE DORTMUND HOUSING MARKET MODEL

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A B S T R A C T

The housing market simulation model described in this paper is part of a larger modeling project conducted at the Institute of Urban and Regional Planning of the University of Dortmund with support by the Sonderforschungsbereich 26 Münster of the Deutsche Forschungsgemeinschaft. The project is directed towards the investigation of the relationships between economic change, locational choice, mobility, and land use in urban regions with the help of a multilevel dynamic simulation model of regional development.

The intraregional migration component of this model system is the housing market model. It consists primarily of an "aging" submodel, in which time-dependent changes of households and housing are modeled in the form of a Markov model with dynamic transition rates, and of the actual housing market or migration submodel, in which individual market transactions are modeled as search processes in a Monte Carlo simulation.

The paper reports on the context, hypotheses, and structure of the model, and on some of its data and calibration problems. The paper was prepared for the Workshop on Housing Market Simulation Models, Heidelberg, March 27-30, 1979.

C O N T E N T S

Introduction

The Dortmund housing market model is an offspring of the Battelle housing market model for the Frankfurt metropolitan region. However, as most children do, it went its own ways, and today it is a model of its own kind differing from the Battelle model in context, philosphy, and structure.

Work on the Dortmund model began in 1977 at the Institute of Urban and Regional Planning of the University of Dortmund as part of a larger research project supported by the Sonderforschungsbereich 26 Münster of the Deutsche Forschungsgemeinschaft. This ongoing project is aimed at the investigation of the relationships between economic (sectoral, technological) change, locational choice, mobility, and land use in urban regions. For this purpose, a spatially disaggregated dynamic simulation model of regional development was 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 programs and policies in the fields of regional development, housing, and infrastructure

in a concrete regional context. It was decided to use the urban region of Dortmund as a study region, including Dortmund and 19 neighboring communities with a total population of 2.4 million.

The intraregional migration component of this model system is the housing market model described in this paper. The decision to model intraregional migrations as transactions on the regional housing market was based on the empirical evidence established by many surveys that household mobility within urban regions, unlike long-distance mobility, is almost exclusively determined by housing considerations, i.e. by the changing housing needs of housholds during their life cycle. Accordingly, the housing market model developed is primarily a micro-analytic model of choice behavior of households and landlords subject to various economic and noneconomic choice restrictions. On the demand side considerable effort has been devoted to modeling the life cycle of households and the development of the households' decision situation and preferences over time. On the supply side the housing stock is changed through aging, public housing programs, or private construction by investors or owner-occupiers. The model differs from other housing market models by the stochastic technique by which it simulates the market-clearing process, and by the fact that it is incorporated into a larger model framework of regional development, industrial location, household mobility, and land use.

The research team is indebted to Battelle-Frankfurt and the City of Frankfurt for the permission to use the aging parts of the Frankfurt housing market model, in the development of which this author was involved while at Battelle until 1976. Also, Battelle gave the permission to use parts of the POLIS urban simulation model developed at Battelle 1969-1973 by the author and others for the public programs and private construction submodels of the present model.

The following description of the model contains three chapters. Chapter one is a brief summary of the whole modeling system of which the housing market model is a part. In chapter two the major hypotheses about the working of the housing market underlying the model are outlined. Chapter three, the actual model description, contains detailed information about model structure, equations, and computational techniques. In chapter four the data sources of the model and the calibration techniques being applied are discussed. However, as calibration of the model is under way, no numerical values of estimated model parameters are given.

The paper was prepared for the Workshop on Housing Market Simulation Models held at Heidelberg, March 27-30, 1979, under the auspices of the West German Ministry of Housing and Urban Development. At the workshop seven housing market models developed at

- the National Bureau of Economic Research, New York,
- the Urban Institute, Washington, D.C.,
- Battelle-Institut e.V., Frankfurt,
- GEWOS GmbH, Hamburg,
- Ifo-Institut für Wirtschaftsforschung, Munich,
- Prognos AG, Basle, and
- the University of Dortmund

were compared and evaluated by their authors and other modeling experts from the US and West Germany.

1. The Model Context

The Dortmund housing market model described in this paper is part of a larger simulation model of regional development, industrial location, household mobility, and land use. The whole model is organized in three spatial levels:

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

(2) a microanalytic model of intraregional location and migration decisions in 29 zones of the urban region of Dortmund ("zonal model"),

(3) a microanalytic model of land use development in one ore 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 labor demand by industry in the 34 labor market regions of Nordrhein-Westfalen and the migration flows between the labor market regions subject to exogenous employment and population projections for the state.

The result of the regional model serve as the framework for the simulation of intraregional location and migration decisions of industry, residential developers, and households in the subsequent "zonal model". The zonal model establishes the second level of the model hierarchy. Its study area consists of the labor market region of Dortmund including Dortmund itself with its ten urban districts plus ten neighboring communities, as well as of nine residential communities outside the labor market region. Thus the study area is divided into 29 zones (Fig. 1).

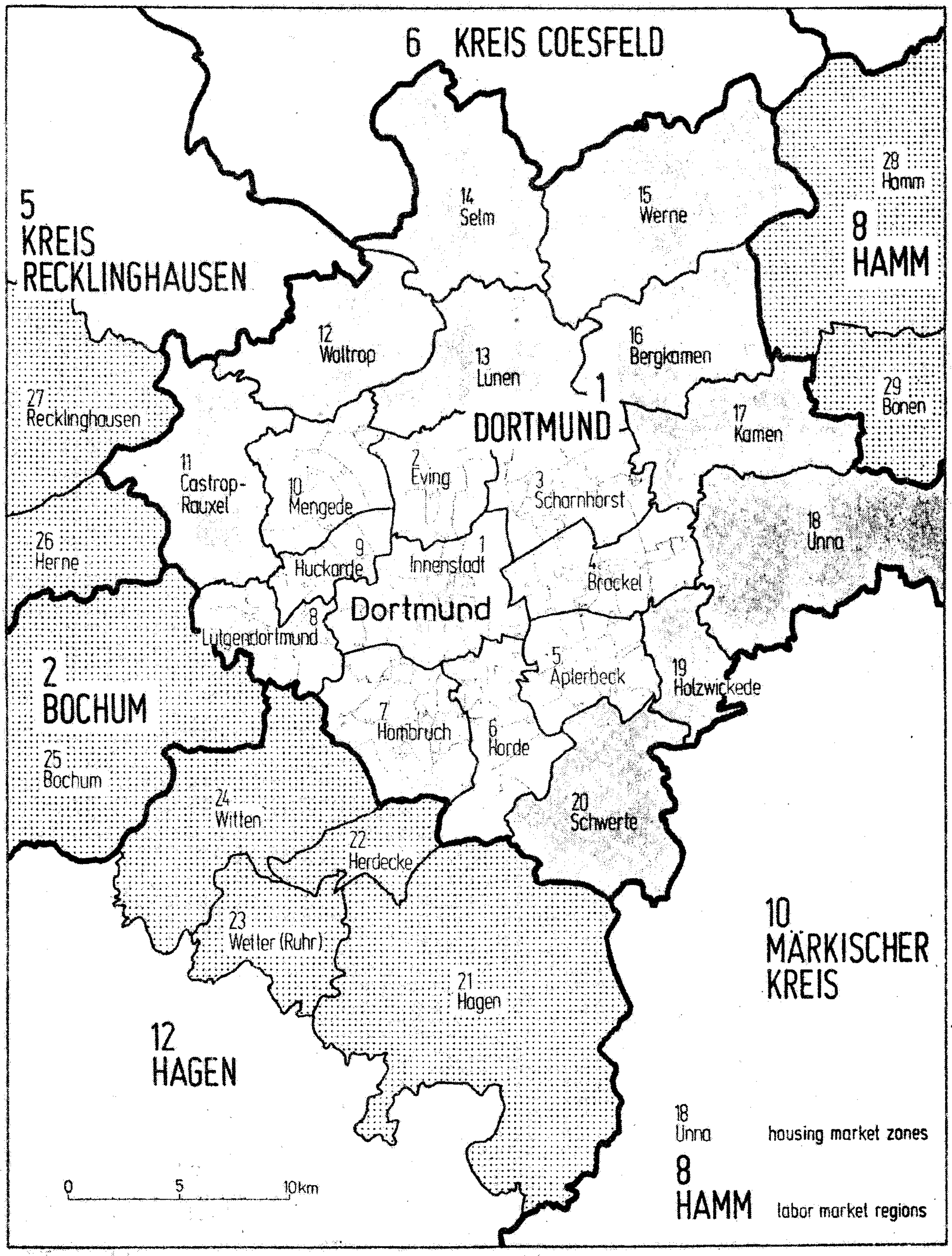

Fig. 1 The Dortmund urban region

The third level of the model hierarchy is the "district model", which is still in the design phase. At this level the land use development allocated to zones in the zonal model is further distributed to individual tracts within one or more zones. Any zone or combination of zones could be included in the district model, but data collection for the district model has been limited to the ten urban districts of Dortmund.

Fig. 2 is a schematic representation of the two model levels now operational, the regional model and the zonal model, and their major model sectors and interrelationships. Both models comprise the sectors employment, population, housing, and infrastructure, but the zonal model also includes industrial and commercial buildings, land use, and transportation. The arrows in the diagram indicate information flows, i.e. impacts. The shaded arrows indicate the information flows between the model levels. A central role in both models plays the concept of attractivity. Attractivity of a region, a zone, or an object in general, is a weighted aggregate of component attributes of the region, zone, or object as seen and evaluated by relevant types of users, and as such the attractivity strongly influences all decisions of the model actors. In the regional model, the attractiviy of a region for migration is mostly affected by job availability, wage level, and the supply of housing and household-serving infrastructure; the attractivity of a region as a location for industry depends on factors such as labor supply, availability of financial aids, and the quality of the housing supply and of the business-serving infrastructure. In the zonal model, the attractivity of a zone as a location as seen by the industrial manager or residential developer is composed of attributes indicating its neighborhood quality such as supply of public facilities or accessibility, while the attractivity of an apartment or a house as seen by a household is an aggregate of its size, quality, and location in relation to its price.

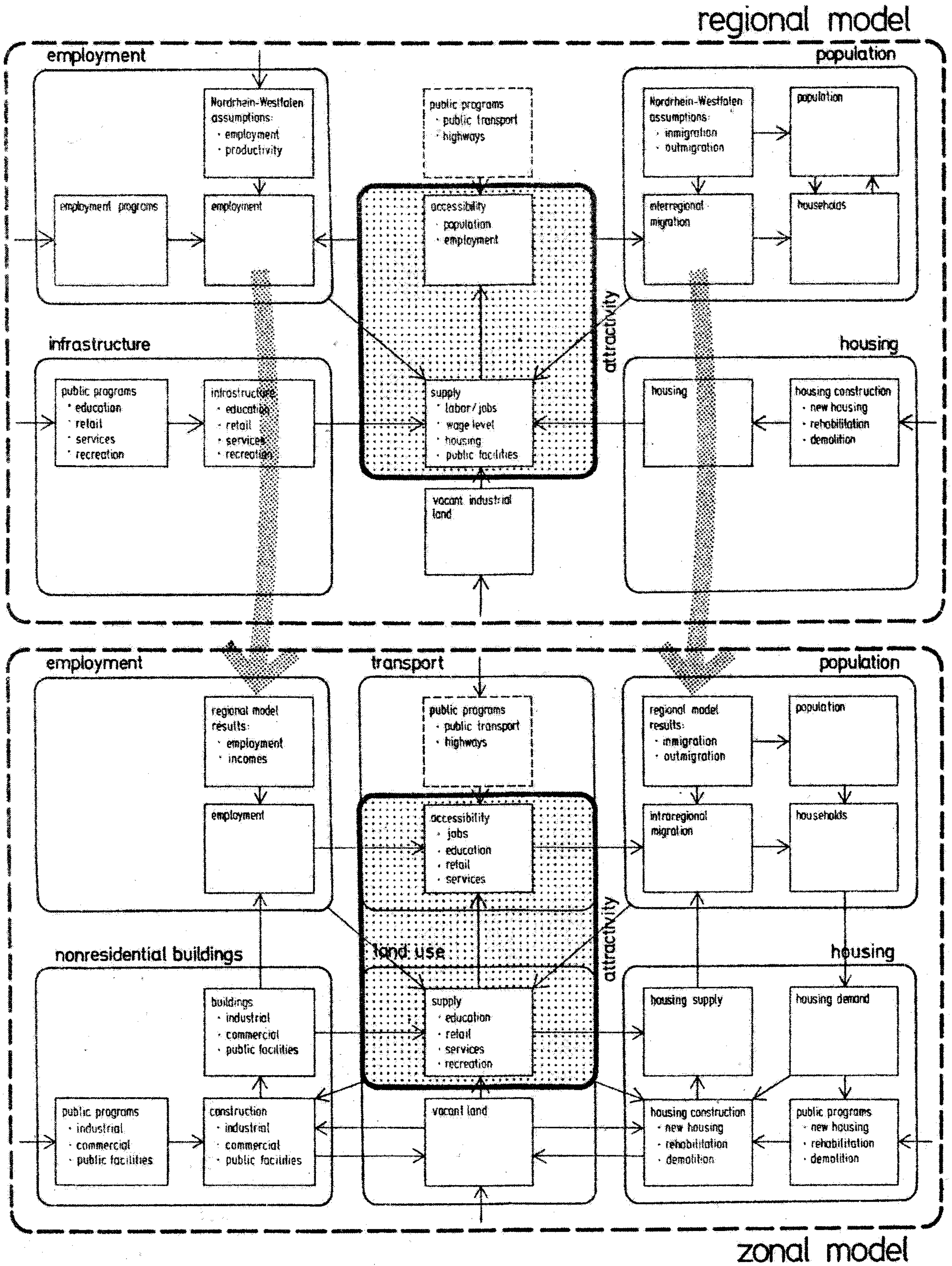

Fig. 2 Regional and zonal model

The 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 refer to points in time, i.e. the beginning and end of each simulation period. The process description parts refer to the time intervals 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 arrows in the diagram indicate sequence of operation as well as information flows.

The simulation begins at the symbol "start" and first passes through an initialization 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 period has been simulated. In this case the model proceeds through a final report phase and closes down at the symbol "stop".

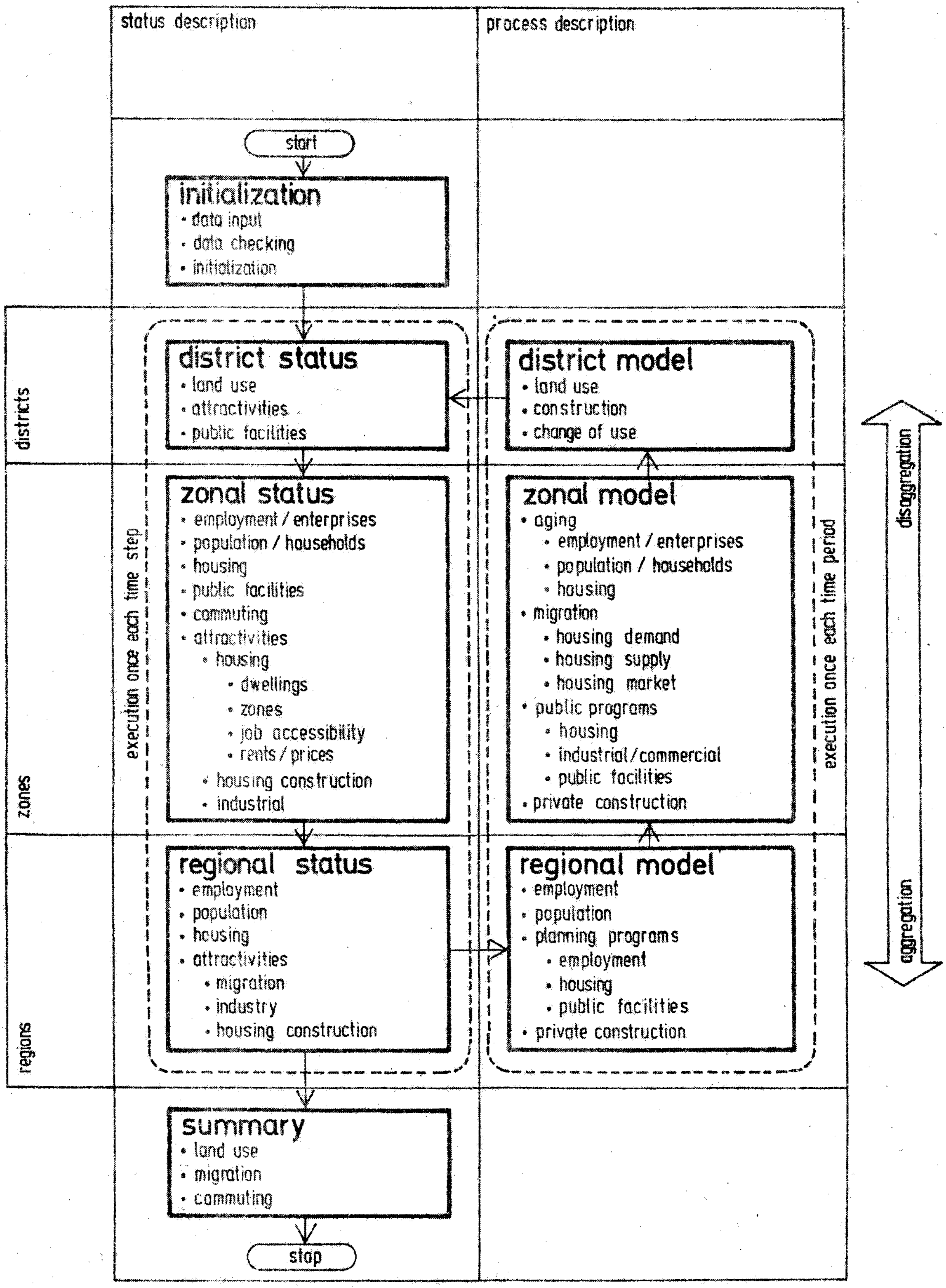

Fig. 3 Model structure: space and time

2. Model Hypotheses

As in this project the housing market is simulated in the context of urban development at large, the hypotheses underlying its design are embedded in a set of hypotheses about the urban development process. These more general hypotheses will be summarized first:

The model building sets out from the hypothesis that the development of human settlement in industrial countries like West Germany is determined by two tendencies:

- The large-scale agglomeration process leads to a growing polarization between the large conurbations and the rural country.
- The small-scale deglomeration process results in high growth rates at the periphery of urban regions at the expense of the city centers.

These two tendencies are not independent of each other. In a way the suburbanization trend is the reverse side of the agglomeration process. Its main causes are:

- high demand for floor space in the city centers for retail and offices, resulting in rising land prices and rents;
- decreasing attractivity of living in the city centers because of traffic congestion, noise, air pollution, unavailability of parking space, lack of recreation facilities like parks, playgrounds, etc.;
- changing living and consumption patterns caused by rising incomes and reductions in daily and yearly work time leading to
  - smaller households, less children,
  - higher housing space requirements per capita,

    - more leisure time, growing interest for recreation, sports, outdoor living,
    - higher emphasis on housing quality and location,
    - growing esteem for "environmental" qualities, such as quietness, clean air, nature;

- improved accessibility of peripheral locations through highway construction and new public transport lines, as well as through higher car availability;

- government support of home ownership through public subsidies and tax benefits;

- the tax and public finance system causing communities to compete against each other for jobs and population.

The consequences of the exodus of people and jobs from the urban core are mono-functionality of the city centers, increased spatial segregation of age and income groups, high expenses for public facilities and transportation, and urban sprawl at the periphery. All this, together with the loss of tax income, makes the suburbanization a serious problem for many cities.

The problem is most severely felt where the agglomeration on the regional level fails to compensate for local losses of employment and population. This is the case in most large Ruhr area cities like Dortmund, which, due to the decline of the coal mining and steel industry, have experienced continuous losses of work places and population during the last fifteen years, while most of the growth of the state was attracted by the large agglomerations in the Rhine valley Düsseldorf and Cologne.

The question is by which theory of urban development the suburbanization process can be explained. In this project it is assumed 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, it is assumed that location decisions of various groups of investors and users are determined by group-specific limitations of information and choice and by multidimensional preference functions 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.

Spatial allocation decisions can be either public or private. Public allocation decisions are all direct (investment) or indirect (legislation, taxation, zoning) programs or policies of the city or other planning authorities. Private allocation decisions are location, migration, or tripmaking decisions by enterprises, households, or individuals which are not or only partly controlled by public authorities. They constitute the market sector of urban development. It consists of three relevant markets: the land and construction market, the housing market, and the transportation market.

The housing market is the place where households trying to satisfy their housing needs interact with landlords trying to make a profit from earlier housing investments. Housing investment or housing production decisions are not part of the housing market, but are effected on the land and construction market, which is separate, but closely related to it. On the land and construction market housing has to compete with other kinds of land or building use.

The modeling of the housing market proceeds from the following hypotheses:

- The housing demand of a household depends on its position in its life cycle and its income.

- The satisfaction of a household with its housing situation can be represented by a utility function with the dimensions housing size and quality, neighborhood quality, location, and housing cost.

- The willingness of a household to move is related to its dissatisfaction with its housing situation. A household willing to move actually does move if it finds a dwelling that gives it significantly more satisfaction than its present one.

- Information and choice on the housing market are limited; the limitations are related to education and income of the market actors. There are on the housing market local as well as social submarkets which are separated by economic and noneconomic barriers.

- After a number of unsuccessful attempts to find a dwelling a household reduces its demand or abandons the idea of a move. Frequently in such cases the location requirement is left unsatisfied and has to be compensated for by commuting.

- Supply on the housing market is highly inelastic: There is practically no price adjustment in short market periods; quantity adjustment is delayed by long construction times.

In general, the housing market, although strongly regulated, fails to satisfy the housing needs of all groups of the population, instead, it tends to reinforce the spatial segregation of social groups.

3. Model Structure

In the zonal model intraregional location decisions of enterprises, developers, and households, and the migration and commuting patterns resulting from them are modeled. This implies the simulation of major changes of population, employment, housing, public facilities, and land use. Such changes can be caused by

- time (aging),
- migration,
- public programs,
- private construction.

These four kinds of change are treated in four separate submodels which form the basic building blocks of the process description part of the zonal model.

The last two of them deal with changes in land use and building stock, i.e. with the land and construction market. They will only briefly be summarized here. The first two contain the housing market model. Fig. 4 shows the sequence of computations in the zonal model and in the two housing market submodels.

3.1 The Aging Submodel

In the housing market model the development of population and housing, excluding public programs and new private construction, is modeled.

Population of each zone is represented in the model as a distribution of households classified by

- nationality (native, foreign),
- size (1, 2, 3, 4, 5+ persons),
- age of head (16-29, 30-59, 60+ years),
- income (none, low, medium, high).

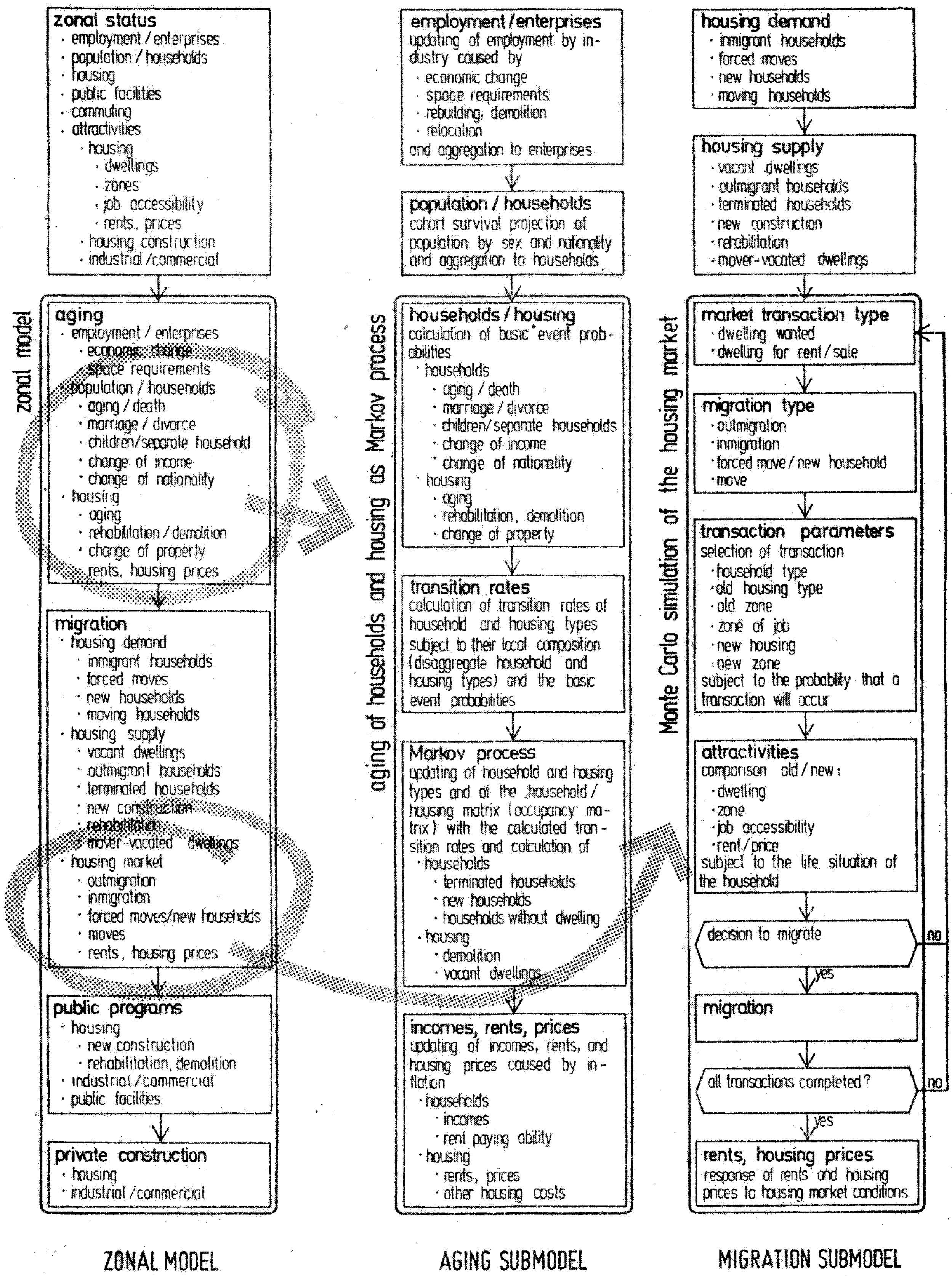

Fig. 4 The zonal model and its housing market submodels

Similarily, housing of each zone is represented as a distribution of dwellings classified by

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

All changes of population and housing during the simulation are computed for these 120 household types and 120 housing types. However, these household and housing types are collapsed to about 30 household and housing types for use in the occupancy matrix.

The occupancy matrix HW of a zone serves to represent the association of households with housing in the zone. Each element of the matrix contains the number of households of a certain type occupying a dwelling of a certain type, the total matrix contains all households occupying a dwelling or all dwellings occupied by a household (Fig. 5). In addition, there exist for each zone a vector H of households currently without a dwelling, and a vector W of dwellings currently without a household, i.e. vacant. The H vector should contain zeros at the outset of each simulation period, but in the W vector there may be vacant dwellings left over from the last period.

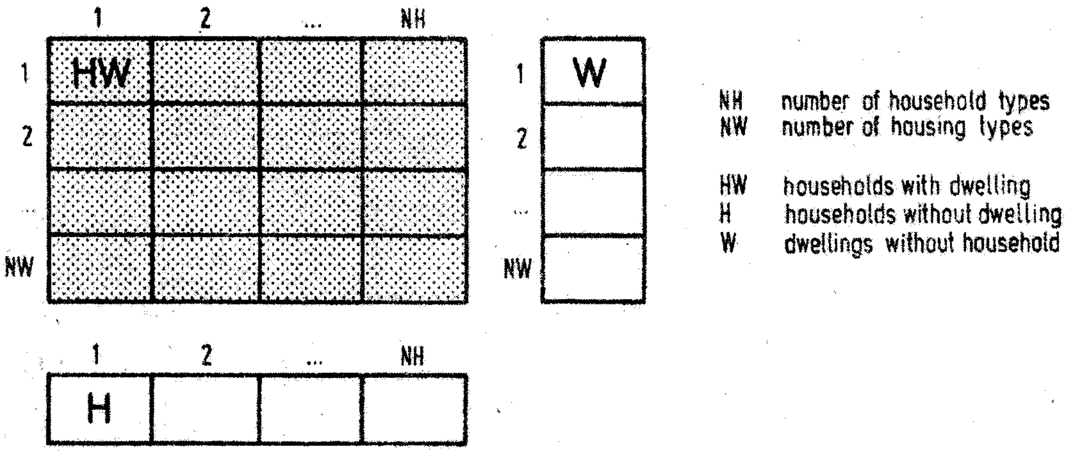

Fig. 5 Households and housing of a zone

All changes occurring to households and housing of a zone during a simulation period can be represented by movements into or out of or within the HW matrix and the H and W vectors.

In the first submodel called the "aging" submodel all changes of households and dwellings are computed which are assumed to result from biological, technological, or long-term socioeconomic trends originating outside of the model, i.e. which in the model are merely time-dependent. For households this includes demographic changes of household status in the life cycle such as birth, aging, death, marriage, and divorce, and all new or disappearing households resulting from these changes, as well as change of nationality or income. On the housing side it includes deterioration and certain types of rehabilitation and demolition. However, all changes of housing occupancy connected with migration decisions are left to the subsequent migration submodel.

The rationale for this procedure is as follows: In reality both kinds of changes are, at least partly, decision-based and occur in a continuous stream of closely interrelated events. However, it is much more convenient to model them separately, each with a different type of model. Of course, that means that feedback between both kinds of changes is ignored, but that seems to be allright, as housing decisions are assumed to depend on household status and income, and not conversely.

The aging submodel therefore serves to update or "age" households and dwellings by one simulation period without moving them relative to each other. This is accomplished by a Markov model with dynamic transition rates between household and housing types. This part of the model was adopted from the Battelle housing market model.

The transition rates are computed as follows: The time-dependent changes to be simulated are interpreted as events occurring to a household or dwelling with a certain probability in a unit of time. These "basic event probabilities" and their expected future developments are exogenously determined. Fifteen basic event probabilities have been identified for each of the three household age groups:

- change of nationality,
- aging,
- marriage,
- birth, native,
- birth, foreign,
- relative joins household,
- death,
- death of child,
- marriage of child,
- new household of child,
- divorce
- rise of income,
- decrease of income,
- retirement,
- new job,

and five for the four housing quality groups:

- rental,
- owner-occupancy,
- deterioration,
- rehabilitation,
- demolition.

Not all household events occur to every household. Some are applicable only to singles, some only to families, some only to adults, some only to children. The demographic event probabilities are checked against the regionwide population projection transmitted from the regional model, and corrected, if necessary. Some household events are followed by housing events, and vice versa: where a household is terminated, a dwelling is vacated, and where a nonvacant dwelling is demolished, a household is left without dwelling.

The basic event probabilities are then aggregated to transition rates HH for households and WW for dwellings using the disaggregate (120-type) household and housing distributions of the zone. A transition rate is defined as the probability that a household or dwelling of a certain type changes to another type in a unit of time. Most events are independent of each other and can be aggregated multiplicatively; but some exclude others, i.e. are the complement of each other. Multiplication of the occupancy matrix HW with the transition rate matrices HH and WW yields the occupancy matrix aged by one simulation period (Fig. 6). Of course, this implies the assumption that all households of a certain type share the same transition rates, no matter in which dwelling they live, and vice versa.

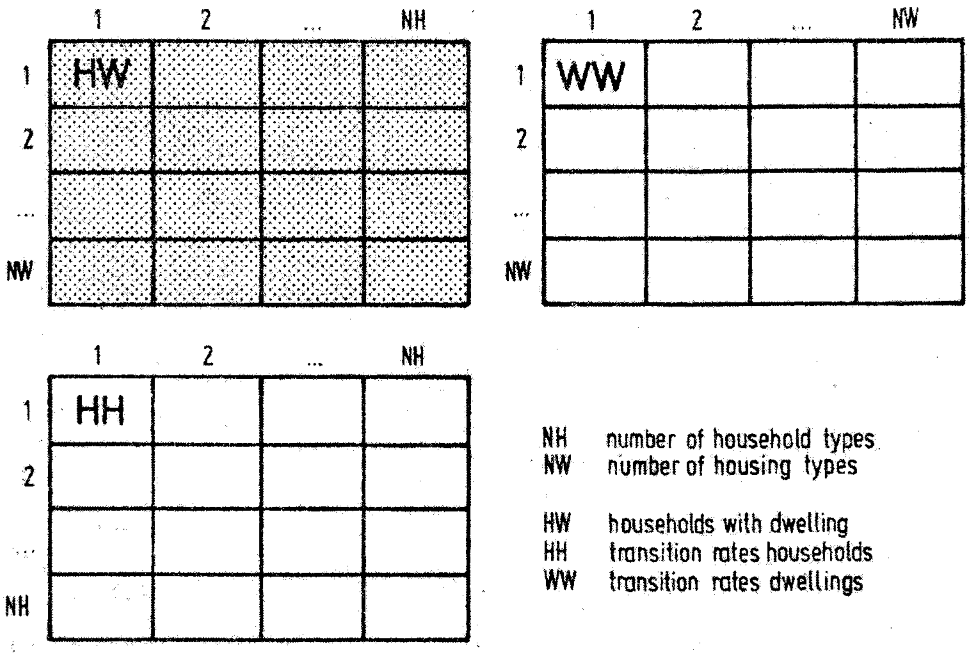

Fig. 6 Aging of households and housing of a zone

Special provisions are necessary for events which imply a change of a household or a dwelling into or out of the HW matrix. Such events are birth, marriage, marriage of child, divorce, death, new household of child, or demolition of a dwelling. Some of these events create a new household without dwelling or a vacant dwelling, i.e. require a change in the H or W vectors. Moreover, also households without dwelling get older, and vacant dwellings deteriorate or may be torn down, i.e. the H and W vectors themselves have to be aged.

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, as well as the incomes and rent paying abilities of all household types.

3.2 The Migration Submodel

In the second, the "migration" submodel, intraregional migration decisions are simulated. Migration is defined as a household's change of location encompassing a change of residence. Consequently, the intraregional migration model is the actual housing market model.

When the migration submodel is entered, the following situation exists: All households and dwellings of all zones have been aged by one simulation period, i.e. now have the time label of the end of the current simulation period. However, no household has yet moved to another dwelling. That is to say: All households have proceeded in their life cycle - they have become older, children may have been born, the family income may have increased - , but their dwellings are still the same or even have deteriorated. Moreover, the expectations of households with respect to size, quality, and location of housing generally have increased as time has proceeded by one period. It may be assumed that many households, which were quite content with their housing situation at the end of the last simulation period, now are dissatisfied with it and are willing to improve it. These households are the potential movers of the current market period.

Households which are more or less satisfied or dissatisfied with their present dwelling are contained in the HW matrix of each zone. Besides, there are the households without dwelling contained in the H vector of each zone consisting of newly founded households looking for a dwelling and of households which unvoluntarily had to vacate their dwellings for various reasons. It is assumed that these households must get a dwelling during this market period under all circumstances.

In addition, there are two vectors transmitted from the regional model: the vector ZH containing households migrating into the region from elsewhere during the simulation period, and the vector AH containing households migrating out of the region. Both vectors have been aged already by another part of the model not discussed here, the regional model interface, to make them compatible with the households aged in the aging submodel. Inmigrating households are treated just like households without dwellings, except that they do not come from a particular zone. Outmigrating households are of interest because they vacate a dwelling.

On the housing side the situation is simpler. A dwelling can either be occupied or be vacant. In the first case it is contained in the HW matrix, in the second case in the W vector of its zone. At the outset of the market period the W vector contains vacant dwellings produced in the current simulation period by household terminations or left over from previous periods. In addition, newly constructed or rehabilitated dwellings which were begun in earlier periods may now have been completed and entered into the W vector.

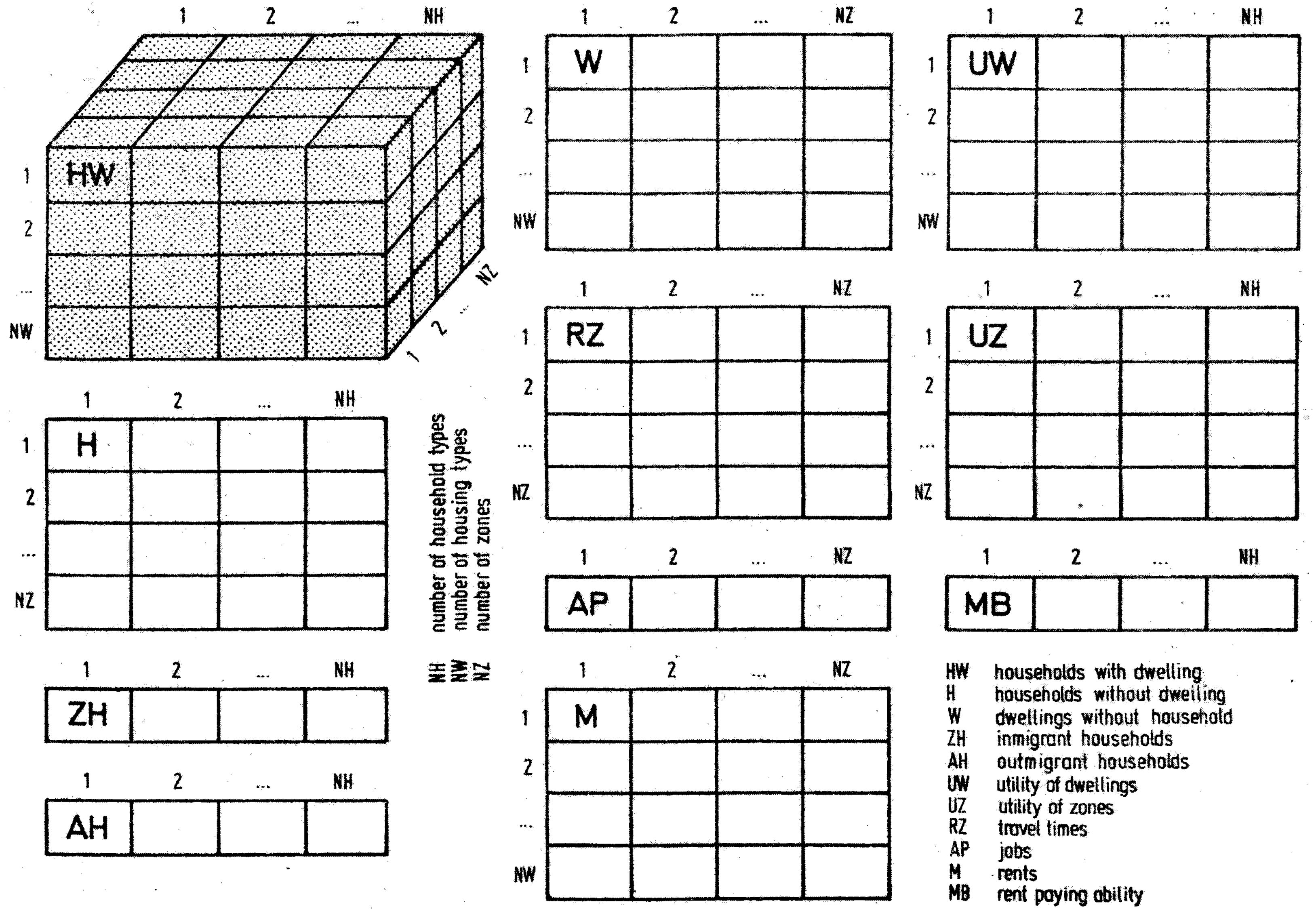

Fig. 7 The housing market

The HW matrix and the H and W vectors of each zone, plus the ZH and AH vectors are a complete representation of households and housing at the outset of the market simulation. Of these the H vectors and the ZH vector clearly represent housing demand, and the W vectors and the AH vector clearly represent the supply side. The HW matrices contain some of both because of the linkage between housing supply and housing demand by vacant dwellings being put on the market with each move. But which of the households in the HW matrices will actually move during the period is not known at this moment.

Fig. 7 illustrates this configuration. Unlike in the aging submodel, now the information of all zones simultaneously has to be available. Therefore, by the additional zonal dimension, the HW matrix becomes threedimensional, and the H and W vectors become matrices. In all vectors and matrices the collapsed or aggregate household and housing structure with about 30 types each is used.

Fig. 7 contains a number of additional vectors and matrices. They provide the information needed to model the decision situation of households and landlords on the housing market and will be explained now.

As it has been indicated in chapter 2, the housing market model is based on the assumption that households, within certain restrictions of information and choice, try to improve their housing situation, or rather their perception of it, i.e. their satisfaction with their housing situation.

The satisfaction of a household with its housing situation is represented in the model by a multidimensional preference function containing the dimensions housing size and quality, neighborhood quality, location, and housing cost. Two of these four dimensions are themselves multiattribute:

- "housing size and quality" is composed of the attributes defining a housing type: type of building, tenure, size, quality.
- "neighborhood quality" is composed of attributes selected or aggregated from state variables of the zones. There are some 300 state variables from the fields of population, employment, buildings, public facilities, transportation, and land use maintained and kept available on a file. In addition, accessibility measures indicating the location of the zone to various activities in other zones have been computed and are also kept on the file.

Evaluation and aggregation of the attributes is performed with the help of an additive multiattribute utility (MAUT) model. The three steps required in the process are illustrated in Fig. 8:

Step 1: From the housing or zone variables V attributes A are extracted by generation functions.

Step 2: The attributes A are evaluated with utility functions yielding one or more utility values UA for each attribute.

Step 3: The utility values UA are aggregated by way of additive weighting functions resulting in one aggregate utility value U.

Obviously, there are as many preference systems as there are household types, as the household types have different housing needs depending on their size, position in the life cycle, and income. The preference systems of housing types therefore differ in their attributes, utility functions, and weighting functions. Moreover, the preference systems change in time, as aspiration levels rise and new priorities come into sight, and these changes are different for different housing types.

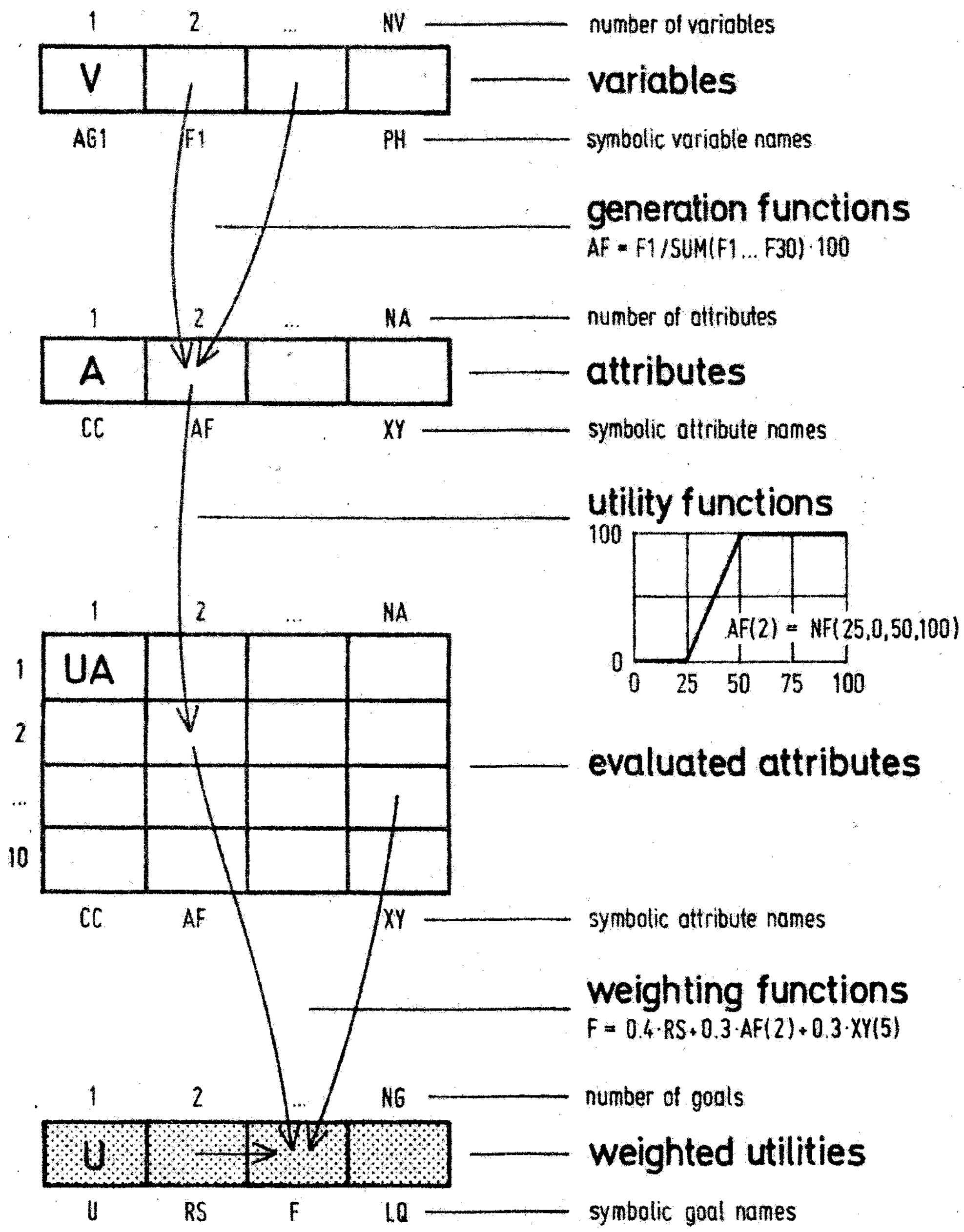

Fig. 8 Computation of utilities

To facilitate the specification of a great number of multiattribute, time-variant preference systems a simple input language consisting of generation functions, utility functions, and weighting functions was designed. The simulation model reads these functions and processes them during the simulation as if they were a part of the program. The language permits to enter the three types of functions in simple mathematical notation like the sample functions in Fig. 8 using symbolic variable names. The generation and utility functions entered apply to all housing types. The weighting functions, however, which select attributes and utility functions for aggregation, are associated with one specific household type only. The language also permits to put time labels on the weighting functions. This makes it possible to specify different attributes, utility functions, or weights for different points in time. The processing program interpolates between distant time labels, which makes it easy to specify gradual changes of preferences.

The two remaining dimensions of housing satisfaction have only one attribute. The "location" dimension is represented by the attribute "job accessibility". A typical utility function for job accessibility looks like that in Fig. 9:

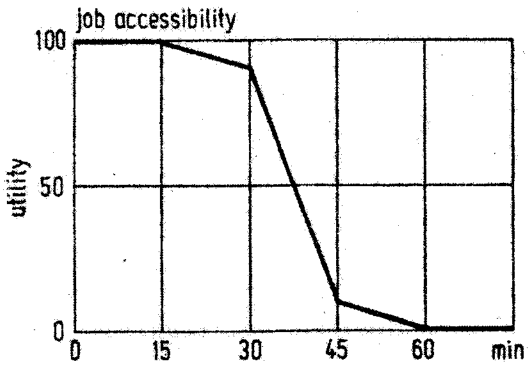

Fig. 9 Utility function of job accessibility (sample)

The explicit consideration of job accessibility in the model takes account of the fact that it is the most important location variable and perhaps the only one which really restricts the choice of a housing location. The second single-attributed dimension is "housing cost". Its only attribute is rent or housing price plus housing operating cost in relation to rent paying ability. Its utility function looks like that in Fig. 10:

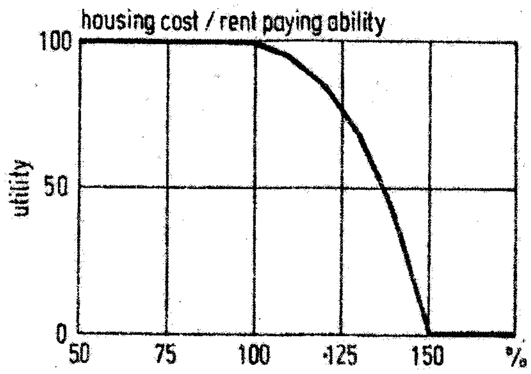

Fig. 10 Utility function of housing cost in percent of rent paying ability (sample)

The matrices UW, UZ, RZ, and M, and the vectors AP and MB serve to make the four dimensions of housing satisfaction available for use in the housing market simulation: UW and UZ contain the housing and zone utilities, respectively, as seen by all household types. These utilities do not change during a simulation period and are computed in advance in the status description part of the model. The utility of job accessibility is computed ad hoc, when it is needed, using the employment vector AP and the travel time matrix RZ. The same applies to the utility of rent which is calculated, whenever it is needed, from the matrix M containing the current rents of all housing types of all zones and the vector MB containing the current rent paying ability of all household types. Both, the M matrix and the MB vector have been updated in the aging submodel.

With the matrices and vectors of Fig. 7 filled all information is available to enter the actual housing market simulation, i.e. the simulation of the market clearing process.

This simulation task poses severe methodological problems. First of all, it is not known at this moment which households of the HW matrix will eventually decide to move, as that certainly depends on the housing supply offered to them on the market. The housing supply, however, is only partly known, because the major part of it consists of dwellings released by moving households during the market process, i.e. depends on just those decisions which are yet unknown. That is to say, the housing market, unlike many other markets, represents a complicated chain exchange system. Second, the level of information of the market actors about the housing market is generally low. That is, households inspect only a relatively small section of the market before making or not making a decision. Third, during a short market period the housing market is inelastic. That is, there is no real bidding process: A dwelling put on the market will not be given to the household bidding highest for it, but the landlord will select a household following a "first come, first served" rule or following other criteria, some of them noneconomic.

The simulation technique selected to deal with these problems is the Monte Carlo technique. It is based on the notion that the total market process can be sufficiently approximated by simulating a representative sample of individual market transactions. To achieve this, the model consists of a sequence of random selection operations by which hypothetical market transactions are generated. The random selection process is controlled by probability distributions which insure that only most likely transactions are selected. In technical terms, the Monte Carlo technique means to play a series of roulette games in which certain outcomes have better chances than others. Of course, this is implemented in the computer by mapping an equally distributed random number into a cumulative probability distribution having the desired properties.

This stochastic kind of simulation has many advantages. Like no other technique it makes it possible to simultaneously consider objective and subjective, economic and noneconomic determinants of the individual decision situation of migrating and nonmigrating households, as well as their restricted information and choice of the housing market. In addition, the technique makes it easy to incorporate psychological hypotheses about the behavior of households following successful or unsuccessful search experiences. In particular, it is possible to model the choice households make between intraregional migration and commuting. Probably the most important advantage of the technique, however, is that it solves the problem of modeling chain exchanges on the housing market in a simple and straightforward manner.

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. There are two ways to start a market transaction: A household decides to look for a dwelling ("dwelling wanted"), or a landlord decides to put a dwelling on the market ("dwelling for rent/sale"). In either case the transaction may result in different kinds of migration: In the case of the household looking for a dwelling the household may be leaving the region ("outmigration") or entering it ("inmigration"), or currently be without a dwelling ("new household/forced move") or occupying one ("move"). The same migration types may result in the case where the landlord offers a dwelling, except that to him outmigrant households are of no interest.

The model starts by selecting a transaction type and a migration type. It is assumed that "dwelling wanted" and "dwelling for rent/sale" are equally likely to occur. The migration type is selected in proportion to the number of transactions to be completed of each type, i.e. the totals of ZH, AH, and H for the first three migration types, respectively. For the fourth or "move" type a tentative estimate of the number of moves as a portion of the HW matrix must be provided.

start of transaction						
dwelling wanted				**dwelling for rent / sale**		
outmigration	inmigration	new household forced move	move	inmigration	new household forced move	move
household of type IH	household of type IH	household of type IH	household of type IH	dwelling of type JW	dwelling of type JW	dwelling of type JW
living in zone IZ		living in zone IZ	living in zone IZ	in zone JZ is inspected by	in zone JZ is inspected by	in zone JZ is inspected by
in dwelling of type IW			in dwelling of type IW	household of type IH	household of type IH	household of type IH
	having a job in zone LZ	having a job in zone LZ	having a job in zone LZ	having a job in zone LZ	having a job in zone LZ	having a job in zone LZ
	inspects dwelling of type JW	inspects dwelling of type JW	inspects dwelling of type JW		living in zone IZ	living in zone IZ
	in zone JZ	in zone JZ	in zone JZ			in dwelling of type IW
	decision	decision	decision	decision	decision	decision
releases old dwelling			releases old dwelling			releases old dwelling
transaction completed						

Fig. 11 Market transactions in the housing market model

Once the transaction type and the migration type have been determined, the remaining parameters of the transaction are selected. A transaction has completely been defined, if the following six parameters are known:

IH	household type
IW	old housing type
IZ	old zone
LZ	zone of job
JW	new housing type
JZ	new zone

A move, for instance, is the migration of a household of type IH, which occupies a dwelling of type IW in zone IZ, and whose head works in zone LZ, into a dwelling of type JW in zone JZ. Not all of the six parameters are required for the other three migration types: Obviously, no IW can be specified for households without a dwelling, nor can IW and IZ for inmigrant households, but it is assumed that inmigrant households have a job in LZ already. Of outmigrant households only IH, IW, and IZ are of interest.

The sequence of selection steps used with each combination of transaction type and migration type is shown in Fig. 11. In each selection step one additional transaction parameter is determined, until the transaction has completely been defined.

In Fig. 12 the selection probability used for each step is given, that is the relative, i.e. yet unnormalized, probability that a certain parameter value will be selected. The following example illustrates how to read Fig. 12: In the case of a household considering a move ("dwelling wanted"/"move"), first the household by type, zone, and dwelling type is selected. The first three selection steps (IH, IZ, IW) indicate that households which are dissatisfied with their neighborhood and dwelling are selected more often than others. In the next step it is asked in which zone LZ the head of the household identi-

	dwelling wanted		dwelling for rent/ sale	
		selection probability		selection probability
outmigration	IH	AH(IH)	-	
	IZ	ΣHW(IH,*,IZ)	-	
	IW	HW(IH,IW,IZ)	-	
inmigration	IH	ZH(IH)	JW	ΣW(JW,*)
	LZ	AP(LZ)	JZ	W(JW,JZ)
	JW	(UW(JW)+UM(JW,*))·ΣW(JW,*)	IH	(UW(JW)+UZ(JZ)+UM(JW,JZ))·ZH(IH)
	JZ	(UW(JW)+UZ(JZ)+UL(LZ,JZ)+UM(JW,JZ))·W(JW,JZ)	LZ	UL(LZ,JZ)·AP(LZ)
new household forced move	IH	ΣH(IH,*)	JW	ΣW(JW,*)
	IZ	H(IH,IZ)	JZ	W(JW,JZ)
	LZ	UL(IZ,LZ)·AP(LZ)	IH	(UW(JW)+UZ(JZ)+UM(JW,JZ))·ΣH(IH,*)
	JW	(UW(JW)+UM(JW,*))·ΣW(JW,*)	LZ	UL(LZ,JZ)·AP(LZ)
	JZ	(UW(JW)+UZ(JZ)+UL(LZ,JZ)+UM(JW,JZ))·W(JW,JZ)	IZ	UL(IZ,LZ)·H(IH,IZ)
move	IH	ΣHW(IH,*,*)	JW	ΣW(JW,*)
	IZ	(100-UZ(IZ))·ΣHW(IH,*,IZ)	JZ	W(JW,JZ)
	IW	(100-UW(IW))·HW(IH,IW,IZ)	IH	(UW(JW)+UZ(JZ)+UM(JW,JZ))·ΣHW(IH,*,*)
	LZ	UL(IZ,LZ)·AP(LZ)	LZ	UL(LZ,JZ)·AP(LZ)
	JW	(UW(JW)+UM(JW,*))·ΣW(JW,*)	IZ	UL(IZ,LZ)·(100-UZ(IZ))·ΣHW(IH,*,IZ)
	JZ	(UW(JW)+UZ(JZ)+UL(LZ,JZ)+UM(JW,JZ))·W(JW,JZ)	IW	(100-UW(IW))·HW(IH,IW,IZ)

IH household type
IW old housing type
IZ old zone
LZ zone of job
JW new housing type
JZ new zone

HW households with dwelling
H households without dwelling
W dwellings without household
ZH inmigrant households
AH outmigrant households
AP jobs

UW utility of dwelling
UZ utility of zone
UL utility of job accessibility
UM utility of rent

* summation or averaging

Fig. 12 The housing market model: Monte Carlo simulation fied in the previous steps might have his job. This step is in fact a simple trip distribution model; the zone of job selected will later restrict the choice of a new housing zone. But prior to that the household decides which housing type JW it wants to look for considering its housing preferences UW and the present market situation. In this step only average rents can be considered, as rents vary between zones, and the actual dwelling has yet to be found. That is done in the final selection step which attempts to find a zone JZ which is close enough to LZ, has a high neighborhood utility UZ for this household, and contains at least one dwelling of type JW at an acceptable price.

The remaining selection steps contained in Fig. 12 can be interpreted in a similar manner. All selection sequences and selection probabilities shown are still tentative and subject to experimentation.

Once the transaction has completely been defined, the migration decision can be made. This is no question for outmigrant households, they do migrate. The remaining households compare their present housing situation with the situation they would gain if they accepted the transaction. As it has been stated, it is assumed that they accept if they can significantly improve their housing situation.

The definition of what is considered a significant improvement remains to be determined by calibration. The measure of improvement is the difference between the housing satisfaction received by the present dwelling and the satisfaction expected from the dwelling offered. Inmigrant households and households without dwelling are given a fictitious "old" housing satisfaction equal to the average satisfaction of all households of the region. It may have been noted from Fig. 12 that the four dimensions of housing satisfaction UW, UZ, UL, and UM are linked additively. However, it is not shown that, if any one of the four dimensions goes to zero, the housing satisfaction is also taken to be zero, in order to ensure that only dwellings which are at least acceptable in all four dimensions are inspected for a transaction. This suggests that a multiplicative model might also be appropriate.

If there is a significant improvement, the household accepts the transaction. In this case all necessary changes in HW, H, ZH, AH, and W are performed. It is a great advantage of this kind of simulation that dwellings vacated with each move or outmigration immediately reappear in the W matrix and are thus released again to the market.

If there is no significant improvement, the household declines. If the transaction type was "dwelling wanted", the household makes another try to find a dwelling, and with each attempt it accepts a lesser improvement. However, no households accept to worsen their housing situation (it may be remembered that rent satisfaction is included in housing satisfaction). After a number of unsuccessful attempts the household abandons the idea of a move, provided that it has a dwelling. Households without a dwelling continue their search with their "old" housing satisfaction reduced to zero, which makes sure that they find a dwelling.

If the household declines, and the transaction type was "dwelling for rent/sale", the landlord tries to find another household, but it is not assumed that he reduces the rent during the market period. If a dwelling type in a zone has been declined by all household types, it is labeled "not marketable" and taken out of the market for this market period.

In all cases the model attempts to find out as soon as possible if a transaction being built up is bound to fail. Therefore, after most selection steps a test is made, and if it fails, the step is repeated, or the transaction is abandoned. By this way only transactions having a good chance of being successfully completed are continued through all selection steps.

After successful or unsuccessful completion of a transaction the next transaction is selected. The market process comes to an end, when there are no more households considering a move. It is assumed that this is the case, when a certain number of transactions have been rejected. This number has to be determined by calibration to match the number of migrations produced in the model with the number of migrations observed in the region.

In a final step rents and housing prices by type and zone are updated in response to the housing demand observed during the market period.

3.3 The Public Programs Submodel

The remaining two submodels of the zonal model are summarized here for completeness, but are not discussed in detail.

In the third, the "public programs" submodel, public programs introduced by the model user are executed. The model accepts the introduction of time-sequenced and localized programs in the fields of housing, industrial and commercial development, and public facilities. Housing programs include new construction, rehabilitation, or demolition by type, zone, and year. The model checks each program for feasibility and stores it for later execution. After an appropriate time delay the program is actually executed, i.e. programs introduced in one period become effective only in a later period. Also modeled in this submodel are changes of rents, housing prices, and land prices resulting from housing construction and rehabilitation programs. The public programs submodel builds upon elements of the respective submodels of the Battelle housing market model and the POLIS urban simulation model.

3.4 The Private Construction Submodel

In the fourth, the "private construction" submodel investment and location decisions of the great number of private developers are modeled, i.e. of the enterprises which erect new industrial or commercial buildings, and the residential developers which build apartments and houses for sale or for rent or for their own use. The present version of this submodel is based on the private construction submodel of the POLIS urban simulation model, but is much more disaggregate to account for the greater number of housing types, industry groups, and land use categories of the current model. In principle, if consists of a sequence of allocation models controlled by the availability of zoned, vacant land and by multi-attribute attractivity measures. Attractivity attributes for developers are suitability for the intended use, location, and price. The volume of private construction is determined by the population and employment projections of the regional model, but is also influenced by the volume of construction produced by public programs. In addition, the volume of housing construction by housing type responds to the housing demand observed on the housing market. Also in this submodel investment decisions of landlords to maintain or improve the quality of their buildings in response to observed demand are modeled. As in the public programs submodel, every construction activity is delayed to account for the time lag between construction decisions and the completion of buildings, i.e. housing investment decisions made in one period do not affect the housing market until a later simulation period. Private housing construction may lead to further changes of rents, housing prices, and land prices.

4. Model Data and Calibration

Data collection and parameter estimation for the housing market model are presently under way. Therefore, only a few preliminary remarks are made about this phase of the modeling work.

The main data sources for the housing market model are tapes of the 1968 housing census and the 1970 census especially prepared for this project by the City of Dortmund. They are the basis for establishing the disaggregate (120-type) distributions of households and housing and of the occupancy matrix of each zone. The model results will be checked against spatially disaggregate population and housing data of the year 1977 also made available by the City of Dortmund.

Establishing the 120-type household distribution for the base year presents no particular problems as far as they are retrieved from these census tapes containing individual data. However, for the neighboring communities, for which such tapes are not available, estimates based on onedimensional distributions taken from published statistical tables have to be made.

A special estimation techniques has been developed to substitute the income information not contained in the census data. By this technique each household is associated with one of the four income groups depending on the employment status and completed education of its head, both which informations are available on the tapes. The four income groups are defined as follows:

1 households having no or a very low earned income; households which live on welfare or unemployment insurance or are supported by relatives; students, apprentices;

2 households having a low income (equivalent to BAT VI and less);

3 households having a medium income (equivalent to BAT III-V);

4 households having a high income (equivalent to BAT II and higher).

Fig. 13 indicates to which income group each combination of employment status and completed education is assigned.

employment status / education completed	not employed, living on: welfare, etc.[1]	pension	property revenues	employed: worker	employee	civil servant	selfemployed	no information
none/no information	1	1	2	1	2	2	2	2
elementary school	1	2	2	2	2	2	2	2
vocational school	1	2	3	2	2	2	3	2
10th grade	1	2	3	2	2	3	3	2
high school	1	3	3	2	3	3	3	3
technical school	1	3	4	3	3	3	4	3
engineering school	1	3	4	2	3	3	4	3
university	1	4	4	2	4	4	4	4

1) welfare, unemployment insurance, support by relatives; students, apprentices

Fig. 13 Estimation of income groups

The four income groups are associated with net incomes expressed in monetary terms at the beginning of each simulation period, taking account of the general development of incomes exogenously determined. Also at the beginning of each period the child allowance and housing allowance each household, depending on its current status, may be entitled to receive are calculated.

Base year data of the housing stock will be taken from the 1968 housing census. As with the household data, tapes containing information on a dwelling-by-dwelling basis are available for Dortmund, while some estimation of distributions will have to be made for the neighboring communities. All information needed to establish the 120-type distribution for each zone is contained on the tapes. However, the fourth dimension constituting a housing type, quality, is an aggregate of a number of dwelling attributes.

The technique applied to determine a housing quality level from dwelling attributes is a multiattribute evaluation model. In Fig. 14 the attributes used in it are listed with their corresponding weights. With each attribute all possible attribute values and their corresponding utility values (in parentheses) are shown.

The result is a utility value scaled between zero and one hundred. This utility value is associated with one of the four quality levels as follows:

0- 53	very low,
54- 73	low,
74- 88	medium,
89-100	high.

These thresholds are selected such that on the high quality level all five primary attributes are satisfied, at least four on the "medium" level, and at least three at the "low" level.

attributes		weights
primary attributes	central heating · no (0) · yes (100)	17
	WC · none or outside (0) · in building (30) · in dwelling (100)	16
	bathroom, shower · no (0) · yes (100)	16
	kitchen, kitchenette · none (0) · 3+ rooms, kitchenette (40) · 1-2 rooms, kitchenette (100) · kitchen (100)	16
	separate dwelling · no (0) · yes (100)	15
secondary attributes	building age · before 1919 (0) · 1919-1948 (25) · 1949-1968 (100)	8
	sewerage · none (0) · private sewerage (40) · public sewer (100)	5
	dwelling or rooms too small · yes (0) · no (100)	4
	basement · no (0) · yes (100)	3
total		100

Fig. 14 Evaluation of housing quality

A special problem is presented by the establishment of the base year occupancy matrix, i.e. the matrix of households of a certain type occupying a dwelling of a certain type. The 1968 housing census contains detailed housing information, but only very limited information on households. The 1970 census, however, contains detailed household, but no housing information. The problem is to match both kinds of census, although they are 18 months apart in time. The idea is first to generate for each zone a household/housing matrix only from the 1968 housing census, and then to "blow it up" to match the 1970 household distribution.

The major parameter estimation tasks, besides estimation of numerous demographic, technical, and monetary parameters, are connected with the estimation of the "basic event probabilities" for the aging submodel and the preference functions for the migration submodel.

The "basic event probabilities" do not pose particular problems as far as they are linked to empirically well established demographic parameters which can easily be checked against exogenous population projections. Much more difficult is the estimation of probabilities for events such as "new household of child", "rise of income", "decrease of income", "retirement", or "new job", for which only few data on the basis of household types exist. However, the only alternative to their approximation to one's best judgment would be to ignore them, which is no real alternative in a model so much based on household decisions.

Even more crucial is the estimation of the preference functions of households for the working of the migration submodel. There can be no doubt that the calibration of hundreds of utility functions and weighting functions even for a past period of time, let alone their extrapolation into the future, would heavily overtax the available data. But again, not to include them in the model would mean to ignore the essential variety of housing needs and tastes, which certainly would be the worse alternative. Besides, this kind of model parameters has one great advantage: Their meaning can be communicated to everyone in everyday language, which makes them amenable to discussion and judgment. Consequently, formal estimation techniques in the strict statistical sense play only a minor role in the calibration of the preference functions, instead, many of the functions will have to be determined by informed judgment, inferences, analogies, expert discussions, and careful checking of plausibility. The empirical foundations of this informal way of model calibration include the numerous surveys of regional and urban housing markets conducted in West Germany in recent years, which contain a wealth of material on migration motives and housing preferences.

Certainly a major problem of the model calibration is the question of sample size for the Monte Carlo simulation. If 30 household types, 30 housing types, and 30 zones are assumed, the number of theoretically possible relations of migration is:

inmigrations	27,000
outmigrations	27,000
households without dwelling	810,000
moves	24,300,000
total	25,164,000

The number of actual migrations in the model region, including inmigrations and outmigrations, is about 370,000 persons per year. However, as the distribution of actual migrations over the theoretically possible relations is not yet known, it is difficult to give an estimate for the size of the sample of transactions to be simulated. It is hoped that a sample of between 50,000 and 80,000 simulated market transactions will give meaningful results not only for net migrations, but also for major migration flows.

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