A SIMULATION STUDY OF MOVEMENT IN THE DORTMUND HOUSING MARKET

by

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Introduction

Two basic kinds of intraregional personal movement can be distinguished: daily travel and migration:

— People make trips for various purposes and usually return home at the end of the day.
— People move from one part of the region to another permanently changing their residence.

Typically, in daily travel models the subjects whose decisions are to be modelled are individual persons. There is a large variety of different modelling approaches to reproduce trip making decisions, trip destination, mode and route selection decisions of travellers on a given transport system, given a certain spatial distribution of land users, and activities in an urban region. Recent advances in computing speed have made highly disaggregate micro simulation approaches feasible, which allow the realistic reproduction of the decision making situation of a particular traveller, under given constraints of activity pattern, travel budget, car availability, and transport supply (Domencich & McFadden 1975, Henscher & Stopher 1979). A major task in the model specification then becomes the development of efficient sampling procedures by which representative travellers are selected for the micro simulation.

In migration models, the subjects modelled should be households, as migration decisions are not made by individual household members, but by the households as a whole. However, as it is difficult to link household-based migration models to person-based biometric population forecasting models, e.g. by headship rates, many present migration models are still person-based. The most prominent types of these are:

— Spatial interaction type migration models which forecast migration flows between geographical subunits i and j as a function of scale quantities of i and j and the distance between i and j (for a review, cf. Magoulas 1974).
— Probabilistic migration models use previously observed migration rates to predict future migration probabilities, i.e. probabilities of transition of a person or a group of persons from one geographical subunit to another (cf. Ginsberg 1971, Rogers 1975).

Both types of models, while perfectly adequate for short and medium term projections, are less appropriate for long-term forecasts, as they in fact fail to grasp much of the causal structure of migration decisions and so are insensitive to changes in the decision environment, in particular to changes in the economic and social factors which determine a decision to move. They do not, for instance, recognize that intra-urban, in contrast to long-distance, migrations are known to be largely determined by housing considerations, while in the majority of cases the location of the job remains the same before and after the move.

The housing location decisions of households are explicitly treated in residential location models and housing market models:

— Spatial interaction type residential location models model locational choices of households, usually as a function of job location

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and housing or land supply, either one-shot, as the original Lowry (1964) model, or incrementally, as its many derivatives (cf. Batty 1976).
— Housing market models typically project housing supply (dwellings by size, quality, location and price) and housing demand (households by size, age and income) separately; potential mover households are placed into a 'mover pool' and assigned to vacant housing by a 'market clearing process' (see, e.g., Kain 1976).

Both these types of models fail to produce migrations as such, i.e. migration flows between spatial subunits i and j, which means that neither model takes account of the previous housing situation of migrant households when modelling the decision to migrate. This may be considered a serious fault, if in fact the previous housing situation of a household not only determines its decision to look for a new dwelling, but also influences its decision behaviour during the search, as has been found in many empirical studies of intraregional migration (e.g., Landwehrmann & Kleibrink 1978, Landwehrmann & Körbel 1980). Besides, these model types are of no interest where socio-spatial effects of intraregional migration are to be studied, as they yield only net migrations.

In the following sections of this paper, a model is presented which combines the accomplishments of the above four model types while avoiding many of their shortcomings. The model produces migration flows by household category as a function of household status, housing budget, previous housing situation, location of job, and of housing supply by housing category, housing location, and housing price between all spatial sub-units, or zones, of an urban area for consecutive points in time.

The paper is a report on work in progress at the Institute of Urban and Regional Planning of the University of Dortmund. A brief outline of the hypotheses underlying the model is followed by a description of the simulation process as it is presently implemented. Finally, preliminary model results are compared with observed data.

The model framework

The intraregional migration model reported in this paper is part of a comprehensive model of regional development organized at three spatial levels (cf. Wegener 1980):

(1) A macroanalytic model of economic and demographic development of 34 labour market regions in the state of Nordrhein-Westfalen;
(2) a microanalytic model of intraregional location and migration decisions in 30 zones of the urban region of Dortmund;
(3) a microanalytic model of land use development in any subset of 171 statistical tracts within Dortmund.

On the first spatial level, employment by industry and population by age, sex, and nationality in each of the 34 labour market regions as well as the migration flows between them are predicted (cf. Schönebeck 1981). These results establish the framework for the simulation of intraregional location and migration decisions on the second spatial level, which again serve to provide the framework for the even more detailed simulation of small-scale land use development on the third level (cf. Tillmann 1981). The simulation proceeds from a base year in two-year increments (periods) over a time span of up to 20 years.

The intraregional migration model is part of the second level of this three-level hierarchical model. On this level, the study area is the urban region of Dortmund, consisting of Dortmund itself with its 12 urban districts and ten neighbouring communities within the labour market region of Dortmund, plus eight zones in four adjacent labour market regions (see Figure 1). The 12 urban districts of Dortmund are relatively homogenous in size, ranging in population between 40,000 and 60,000, while the remaining zones vary considerably in population between about 15,000 and over 400,000 (Bochum). The whole urban region has a population of about 2.4 million.

For these 30 zones, the model simulates intraregional location decisions of industry, residential developers, and households, the resulting migration and commuting patterns, the land use development, and the impacts of public policies in the fields of industrial development, housing, and infrastructure. This is done in four submodels:

(a) *The Aging Submodel* — In the first, the aging submodel all changes of the model variables are computed which are assumed to result from biological, technological, or long-term socio-economic trends originating outside the model, i.e. which are not treated as decision-based in the model. These changes are effected in the model by probabilistic aging or updating models with dynamic transition rates. At present there are three such models, for employment, population, and households/housing.

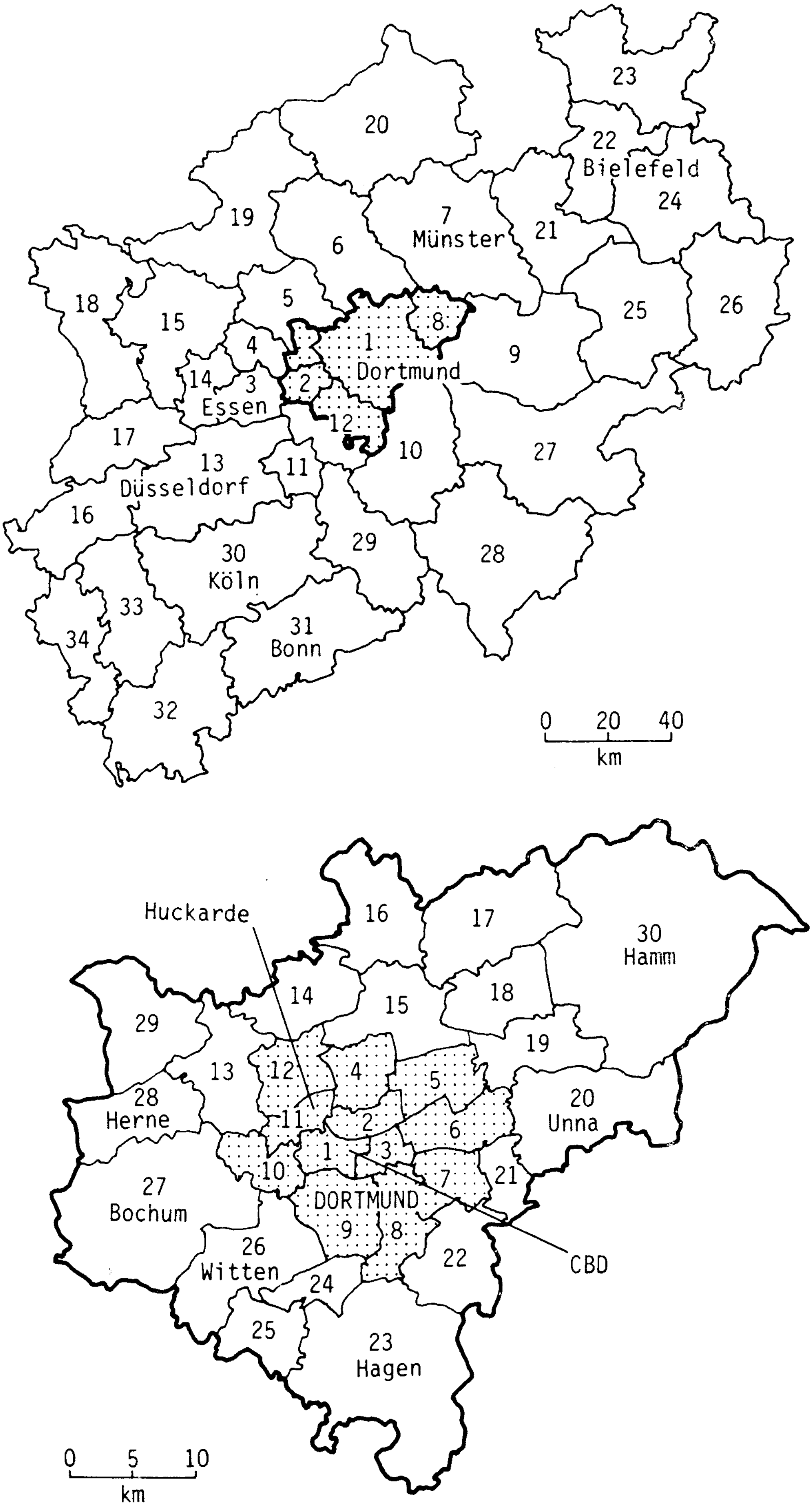

Fig. 1. Labour Market Regions in Nordrhein-Westfalen (top) and the zones of the Dortmund urban region model (bottom).

(b) *The Migration Submodel* — In the second, the migration submodel intraregional migration decisions of households are simulated as search processes on the regional housing market. Thus the migration submodel is at the same time a housing market model.
 The results of the migration submodel are intraregional migration flows by household category between housing by category in the 30 zones.
(c) *The Public Programmes Submodel* — In the public programmes submodel, a large variety of public programmes in the fields of employment, housing, health, welfare, education, recreation, and transport specified by the model user are processed.
(d) *The Private Construction Submodel* — In the private construction submodel, investment and location decisions of the great number of private developers are modelled, i.e. of enterprises which erect new industrial or commercial buildings, and of residential developers who build apartments and houses for sale or for rent or for their own use. Thus the submodel is a model of the regional land and construction market.

In this paper, only the migration or housing market submodel will be discussed in some detail. For details on the other three submodels, see Wegener (1980, 1981).

Model hypotheses

In the migration, or housing market, submodel, intraregional migration decisions of households are modelled. It is important to note that this submodel includes only what is usually called the 'market clearing process' of the housing market: Aging of households and of the housing stock has previously been performed in the aging submodel, while changes of the housing supply by new construction, demolition, rehabilitation, or change of building use will be executed in the subsequent public programmes and private construction submodels.

The principal actors of the migration or housing market model are the households representing housing demand and the landlords representing housing supply. The design of the model was based on the following hypotheses about their behaviour:

— The housing demand of a household depends mainly 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, neighbourhood 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.
— After a number of unseccessful attempts to find a dwelling a household reduces its demand or abandons the idea of a move.
— Households have only limited information of the housing market; this limitation is related to their education and income.
— There are on the housing market local as well as social submarkets which are separated by economic and non-economic barriers.
— 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.

Model data

Housing demand and housing supply are represented in the housing market model as households and housing classified by type. There are M household types and K dwelling types aggregated from four-dimensional distributions of households 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);

and of dwellings 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);

respectively, with K and M presently each having a value of 30 (see Figure 2). In addition, there exists for each zone a matrix $\underset{\sim}{R}$ of dimension $M \times K$ called the occupancy matrix representing the association of households with housing in the zone (cf. Gnad & Vannahme 1981).

At the outset of the housing market simulation, all households and dwellings in the matrix $\underset{\sim}{R}$ have been aged by one simulation period in the aging submodel: they have become older, children may have been born, the family income may have increased, or other events may have

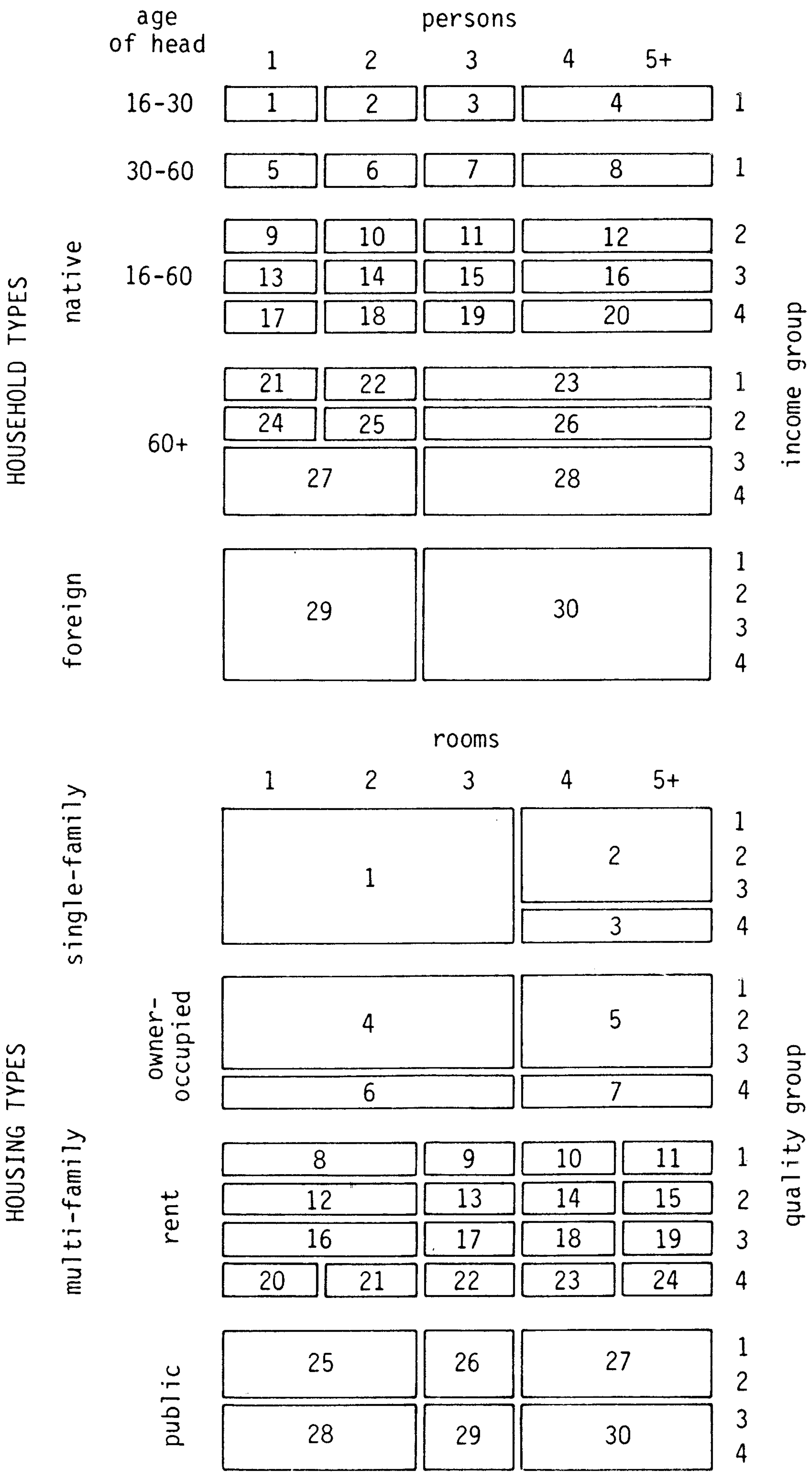

Fig. 2. Household and housing types in the migration Submodel.

occurred (cf. Wegener 1981). In other words: all households have proceeded in their life cycle. However, their dwellings are still the same, as no household has yet moved to another dwelling. Some dwellings may even have deteriorated during the period. Moreover, the expectations of households with respect to size, quality, and location of housing generally will have increased. It may therefore be assumed that many households will have become dissatisfied with their housing situation and are willing to improve it.

Besides the households in the matrix $\underline{R}$, there are households without dwellings stored in a vector $\underline{H}$ and vacant dwellings contained in a vector $\underline{D}$ for each zone. Households without dwellings may be new households generated by the aging submodel or former subtenants; vacant dwellings may be newly constructed or left over from the previous simulation period. In addition, there are two $M \times 1$ vectors of households specified at the top level of the three-level model hierarchy: the vector $\underline{H}^e$ containing households migrating into the region from elsewhere during the simulation period, and the vector $\underline{H}^o$ containing households migrating out of the region.

It should be noted that for processing in the housing market model the matrices $\underline{R}$ of all zones are stored three-dimensionally with the zonal dimension as the third subscript. Similarly, the vectors $\underline{H}$ and $\underline{D}$ become two-dimensional with the zonal dimension as the second subscript. Then, $\underline{R}$, $\underline{H}$, $\underline{D}$, $\underline{H}^e$, and $\underline{H}^o$ are a complete representation of households and housing at the outset of the market simulation. Of these, $\underline{H}$ and $\underline{H}^e$ clearly represent housing demand, and $\underline{D}$ and $\underline{H}^o$ clearly represent housing supply. The matrix $\underline{R}$ represents supply as well as demand because of the linkage between housing supply and housing demand, through vacant dwellings being put on the market at each move. But which of the households in $\underline{R}$ will actually move during this market period is not known at this time.

In addition to the above information on households and housing, information on the housing preferences and housing budgets determining the decision behaviour of the model actors has to be provided for the model. This is accomplished by calculating for each combination of household types, housing types, and zones, i.e. for each element of the three-dimensional matrix $\underline{R}$, a complex indicator u_{mki} representing the satisfaction of a household with its housing situation. This indicator consists of a multidimensional attractiveness function containing the dimensions of housing size and quality, neighbourhood quality and location, and housing cost. Two of these three dimensions are themselves composed of more than one attribute:

— Housing size and quality is composed of the attributes defining a housing type: type of building, tenure, quality, size.
— Neighbourhood quality and location is composed of attributes selected or aggregated from zonal variables from the fields of population, employment, buildings, public facilities, transportation, and land use, as well as of accessibility measures indicating the location of the zone to the work places and to retailing, educational, and recreational facilities in other zones.

The remaining dimension, housing cost, has only one attribute: rent or housing price in relation to income.

One thing that is still lacking is information related to the spatial preferences of migrant households. Obviously, only very general measures of accessibility referring to all other zones can be included in the above index of housing satisfaction, which would certainly not suffice to reproduce the distinct spatial pattern displayed by intra-regional migration flows. Therefore, a further measure is required to control the spatial behaviour of the model actors. This measure is called migration distance and will be discussed in the next section.

Migration distance

In urban areas of industrialized countries with highly developed transport infrastructure and public and private services being almost ubiquitous, accessibility has ceased to be a scarce resource. One should expect, therefore, that spatial aspects tend to play a decreasing role in intra-regional migration decisions of households in comparison with other factors such as housing quality or neighbourhood amenities. But quite to the contrary, observed intraregional migration patterns show a persistent bias towards short-distance moves with a very large proportion of them being within the same neighbourhood.

There seem to be two major causes for this phenomenon. First, households have only very limited information about the housing market. It is known that most households looking for a dwelling in fact inspect only very few offered dwellings, and these are likely to be offered to them through friends or relatives. Quite naturally, most of these dwellings will be situated in the immediate neighbourhood. In addition, as most people move to improve their housing situation with respect to dwelling size and quality, they prefer to stay within or at least near to their accustomed neighbourhood in order to maintain their social relationships as much as possible after the move.

The second major cause for the prevalence of short-distance moves must be attributed to job location. As most intra-urban moves are not connected with a simultaneous change of job, the maximum acceptable travel time from the existing place of work will in most cases restrict the search field for a new housing location.

It is obvious that the two objectives, viz. to find a dwelling close to the old dwelling and within acceptable distance to the place of work, may be in conflict when the present housing and the place of work are not in the same zone. Consider an average configuration like the one illustrated in Figure 3.

Here, the old dwelling at point A and the place of work at point B are separated by the present commuting distance AB. In this schematic representation, travel times from A and B, are indicated by circular contours of utility surfaces, travel times having been transformed by travel time utility functions such as those in Figure 4.

In Figure 3, the solid utility contours encircle that area in which commuting times to job location B would be acceptable; the broken contours define that area which is reasonably close to the old dwelling at A. Where will the household most likely begin its search for a new dwelling?

There are two conventional answers to this question. Spatial interaction type migration models consider only the utility surface around the old dwelling at A, i.e. the broken contours. Spatial interaction type residential location models, however, consider only the utility surface around the place of work at B, i.e. the

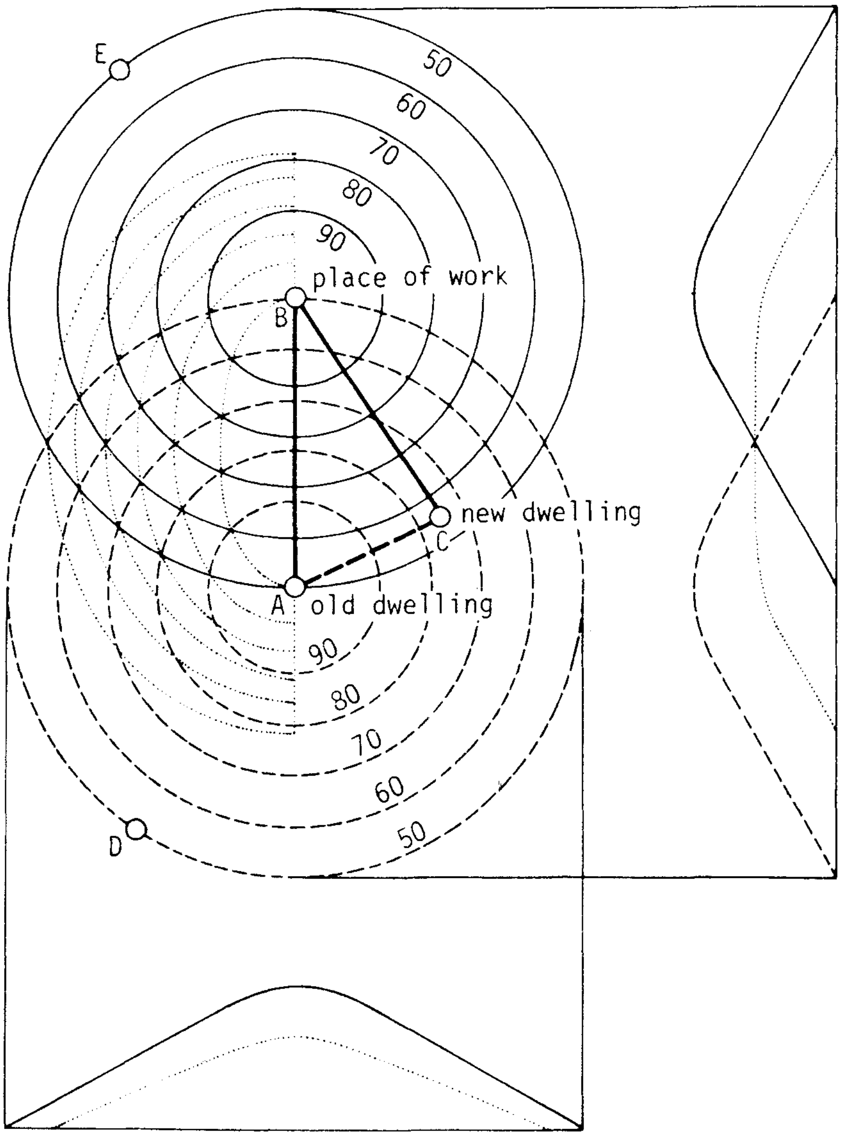

Fig. 3. Commuting distance and migration distance, schematic.

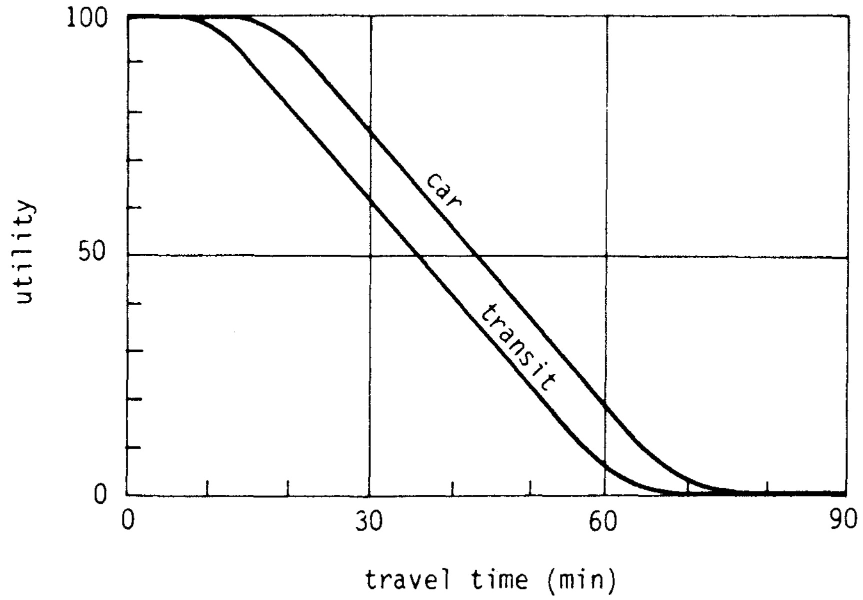

Fig. 4. Utility functions of travel time.

solid contours. Both model types may lead to unlikely results. For instance, for the interaction migration model point D at the left bottom may be an acceptable destination for migrants from A, although it clearly is too far away from the place of work at B. Similarly, the residential location model would suggest that any point on a given utility contour around B, including point E at the top left, has the same locational merit as a place of residence, although to move there would force a household coming from A to completely give up its neighbourhood relations.

Obviously, the area with the highest search probability is situated where the two utility surfaces overlap. Point C may thus be rightly considered a likely location for the new dwelling. The question is how the two kinds of spatial utility can be aggregated. Simple unweighted addition yields the elliptical dotted utility contours with AB as the major axis as indicated on the left hand side of Figure 3.

In the simulation model, the problem is slightly more complicated as the places of work of the households living at A are known only probabilistically as a distribution of destinations of home-to-job trips originating in A. Therefore, some measure of average commuting time between a new housing location and all possible places of work needs to be developed. At present the following formulation is being investigated :

$$w_{ii'} = \sum_j \frac{T_{ij}}{\sum_j T_{ij}} v(c_{i'j}) \tag{1}$$

where i is the present home zone, j is the work zone, and i' is the potential new housing zone. The T_{ij} are home-to-job work trips from zone i to zone j presently being estimated using a production-attraction constrained interaction model of the form

$$T_{ij} = A_i B_j O_i D_j \exp(\lambda v(c_{ij})) \tag{2}$$

where the O_i are workers living in zone i, the D_j are jobs located in zone j, and the A_i and B_j are the usual balancing factors needed to satisfy the marginal constraints (cf. Wilson 1970, Batty 1976). The function $v(c_{i'j})$ is the utility function of travel time mentioned above.

The interpretation of $w_{ii'}$ is straightforward. It is simply the average utility with respect to commuting time afforded at zone i' if a representative sample of households moved from zone i to zone i' without changing their jobs. Thus, $w_{ii'}$ expresses the attractiveness of zone i' as a new housing location with respect to job accessibility for a household now living in zone i whose head has a job in zone j. For clearer identification, $v(c_{ij})$ will be called the commuting distance between i and j, and $w_{ii'}$ will be called the migration distance between i and i'. Note that the term distance is used here to denote utilities scaled between, say, 0 and 100 for the worst and the best case, respectively.

The utility surfaces of $v(c_{ij})$ and $w_{ii'}$ differ quite substantially. Figure 5 shows the two utility surfaces for zone 11, Huckarde. It can be seen that the utility surface of $w_{ii'}$ is less sloped and has its peak not in zone 11 itself, but in the inner city of Dortmund, zone 1. The latter is entirely plausible as most work trips originating in zone 11 in fact go to the CBD, which means that moving in that direction will usually result in a reduction of work trip length.

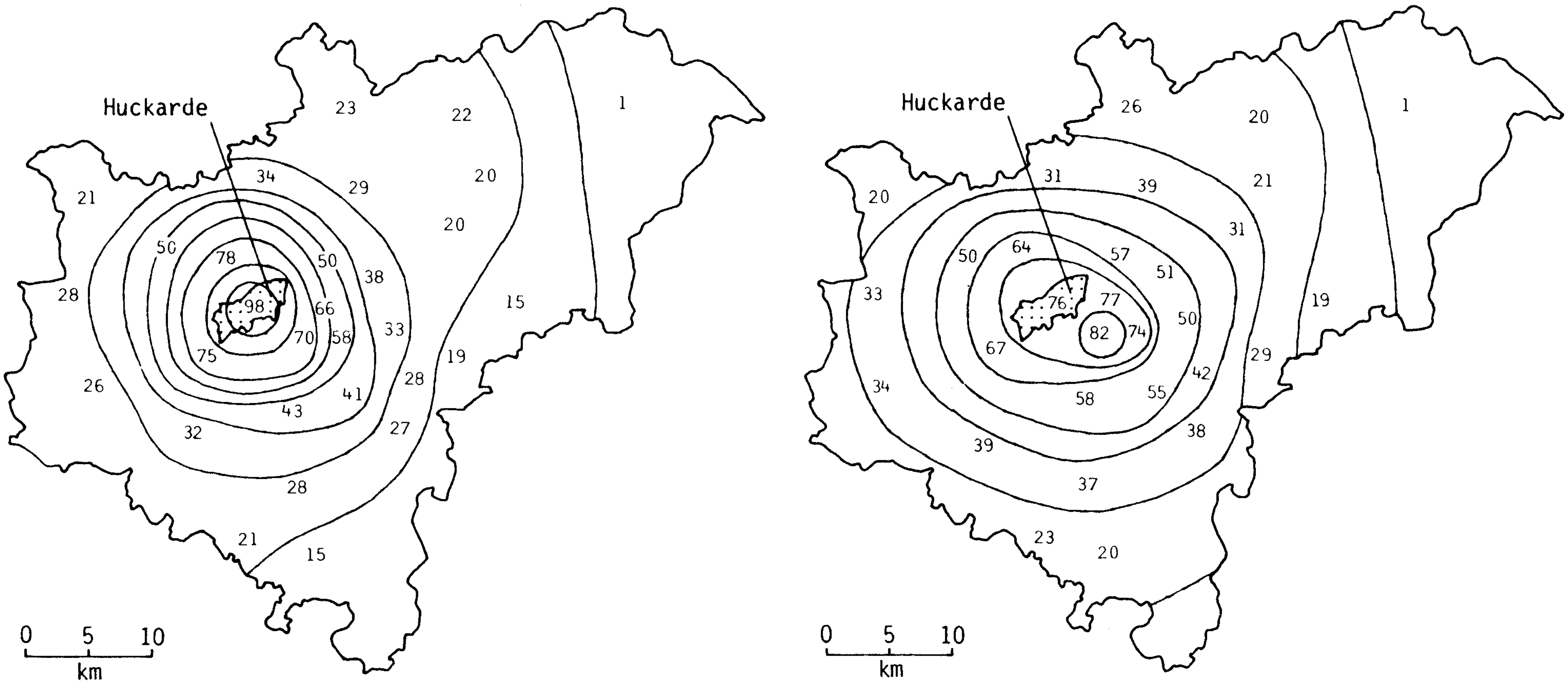

Fig. 5. Utility surfaces of commuting distance (left) and migration distance (right) for zone II. Huckarde.

Following the reasoning underlying Figure 3, for use in the migration submodel, commuting distance and migration distance are aggregated into a matrix of locational attractiveness $\underset{\sim}{s}$ of dimension $I \times I$, where I is the number of zones in the region. One element of this matrix, $s_{ii'}$, expresses the locational attractiveness of zone i' as a new residential location for households now living in zone i. Unweighted addition is presently used for the aggregation, but other aggregation rules may prove to be more appropriate. The measure $s_{ii'}$ will be called the modified migration distance between i and i'.

The micro simulation

The model for the simulation of the market clearing process of the regional housing market uses the Monte Carlo micro simulation technique. The approach 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 likely transactions are selected.

The basic unit of the simulation is the market transaction. 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 offer a dwelling ('dwelling for rent or sale'). In either case the transaction may result in different kinds of migration: The household may leave the region ('outmigration') or enter it ('inmigration'), or currently be without a dwelling ('new household or forced move'), or occupying one ('move').

The model starts by selecting a transaction type and a migration type. The first transaction type is chosen at random. The migration type is selected in proportion to the number of migrations to be completed of each type. Once the transaction type and the migration type have been determined, the remaining parameters of the transaction are selected. A transaction has been completely defined if the following six parameters are known:

m household type	j zone of job
k old housing type	k' new housing type
i old zone	i' new zone

In each step one additional parameter is determined, until the transaction has been completely defined. The following example illustrates this: In the case of a household considering a move ('dwelling wanted', 'move') first the household by type, zone, and dwelling type is selected with

$$p(k|mi) = \frac{R_{mki}\exp(\alpha(100-u_{mki}))}{\sum_k R_{mki}\exp(\alpha(100-u_{mki}))} \quad (3)$$

being the probability of dwelling type k to be selected if household type m and zone i are already known, which is to say that households which are dissatisfied with their housing situation are selected more often than others. In the next two steps it is asked in which zone j the head of the household might have his job and how this may restrict the choice of a new housing zone. With the help of the modified migration distance $\underset{\sim}{s}$ these two selection steps can be collapsed into one with

$$p(i'|mki) = \frac{\sum_{k'} D_{k'i'}\exp(\beta s_{ii'})}{\sum_{i'}\sum_{k'} D_{k'i'}\exp(\beta s_{ii'})} \quad (4)$$

being the probability of zone i' being selected as a new housing zone where m, k, and i are given and zone j assumed to be the work place of the household head. In the final selection step the household attempts to find a dwelling in zone i' with

$$p(k'|mkii') = \frac{D_{k'i'}\exp(\gamma u_{mk'i'})}{\sum_{k'} D_{k'i'}\exp(\gamma u_{mk'i'})} \quad (5)$$

being the probability of dwelling type k' being selected if all other parameters are given.

Once the transaction has been completely defined, the migration decision is made. This is not a valid question for outmigrant households, as they do migrate. All other households compare their present housing situation with the situation they would gain if they accepted the transaction. It is assumed that they accept if they can significantly improve their housing situation.

If there is a significant improvement, the household accepts. In this case all necessary changes in $\underset{\sim}{R}$, $\underset{\sim}{H}$, $\underset{\sim}{H}^e$, $\underset{\sim}{H}^o$, and D are immediately performed. Dwellings vacated with a move or an outmigration reappear in the matrix $\underset{\sim}{D}$ and are thus again released to the market.

If there is no improvement, the household declines. It makes another try to find a dwelling, and with each attempt it accepts a lesser improvement. After a number of unsuccessful

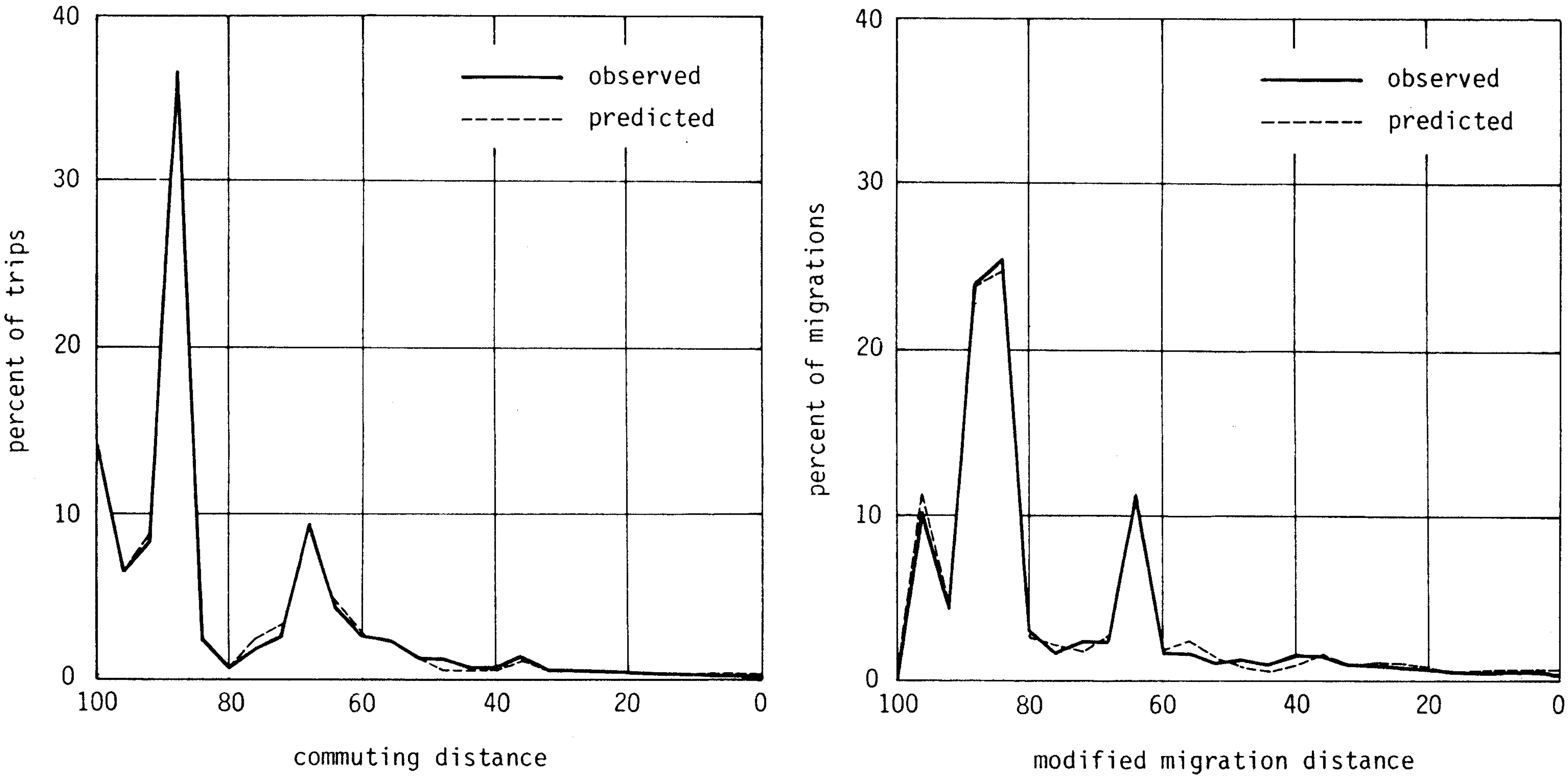

Fig. 6. Model results vs. reality: Frequency distributions of commuting distance (left) and modified migration distance (right). Dortmund region, 1970-1971.

attempts it abandons the idea of a move. The landlord tries to find another household, but he does not reduce the rent during the market period.

After the successful completion of a transaction, the next transaction of the same transaction type is selected. After each unsuccessful completion of a transaction, the transaction type is changed. The market 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 has been rejected. This number is determined by calibration to match the number of migrations produced by the model with the number of migrations observed in the region.

The results of the housing market simulation serve to calculate migration flows by household type between different housing types or submarkets in the zones. After the simulation, all migration-induced changes of the age and household distributions of the zones are performed.

Simulation experiments

Presently, the migration submodel is tested together with the other three submodels in a series of simulation experiments starting with the year 1970 as the base year.

In this section of the paper, the work trips in the base year and the migration flows during the first simulation period, 1970-1971, as produced by the model, are compared with observed data.

Figure 6 shows frequency distributions of work trips by commuting distance $v(c_{ij})$ and of migration flows by modified migration distance $s_{ii'}$. The model results are confronted with actual data taken from the 1970 census and the 1970 and 1971 migration statistics, respectively.

Obviously, there is a close correspondence between the observed and predicted frequency distributions as indicated by the goodness-of-fit statistics presented in Table 1.

These results suggest that the model well reproduces the space-discounting behaviour of commuters and migrants in the region. However, the frequency distributions reflect only one dimension of the spatial interaction pattern in the region, and not the most important one. For assessing the predictive performance of the model it is much more relevant to look at

Table 1. Goodness-of-fit of frequency distributions of distance.

model	n	r^2	t	mean distance	
				observed	predicted
percent work trips by commuting distance v	50	0.9986	184.00	79.57	79.32
percent migrations by modified migration distance s	50	0.9961	107.72	74.50	74.03

Table 2. Goodness-of-fit of work trip and migration flows.

model: volume	n	r^2	t	mean absolute error %	percent errors in error range		
					< 30 %	30-100 %	> 100 %
work trips:							
< 1,000	854	0.6008	35.8	63.3	22.5	52.4	25.1
1,000-5,000	70	0.7580	14.6	19.0	71.4	28.6	0.
> 5,000	37	0.9986	159.9	5.0	100.0	0.	0.
all flows	961	0.9977	639.9	13.6	29.1	48.6	22.3
migrations:							
< 1,000	860	0.4277	25.3	78.2	14.4	55.3	30.3
1,000-5,000	68	0.5680	9.3	69.1	30.9	0.	
> 5,000	33	0.9620	28.0	12.9	87.9	21.1	0.
all flows	961	0.9757	196.3	22.8	20.8	52.0	27.2

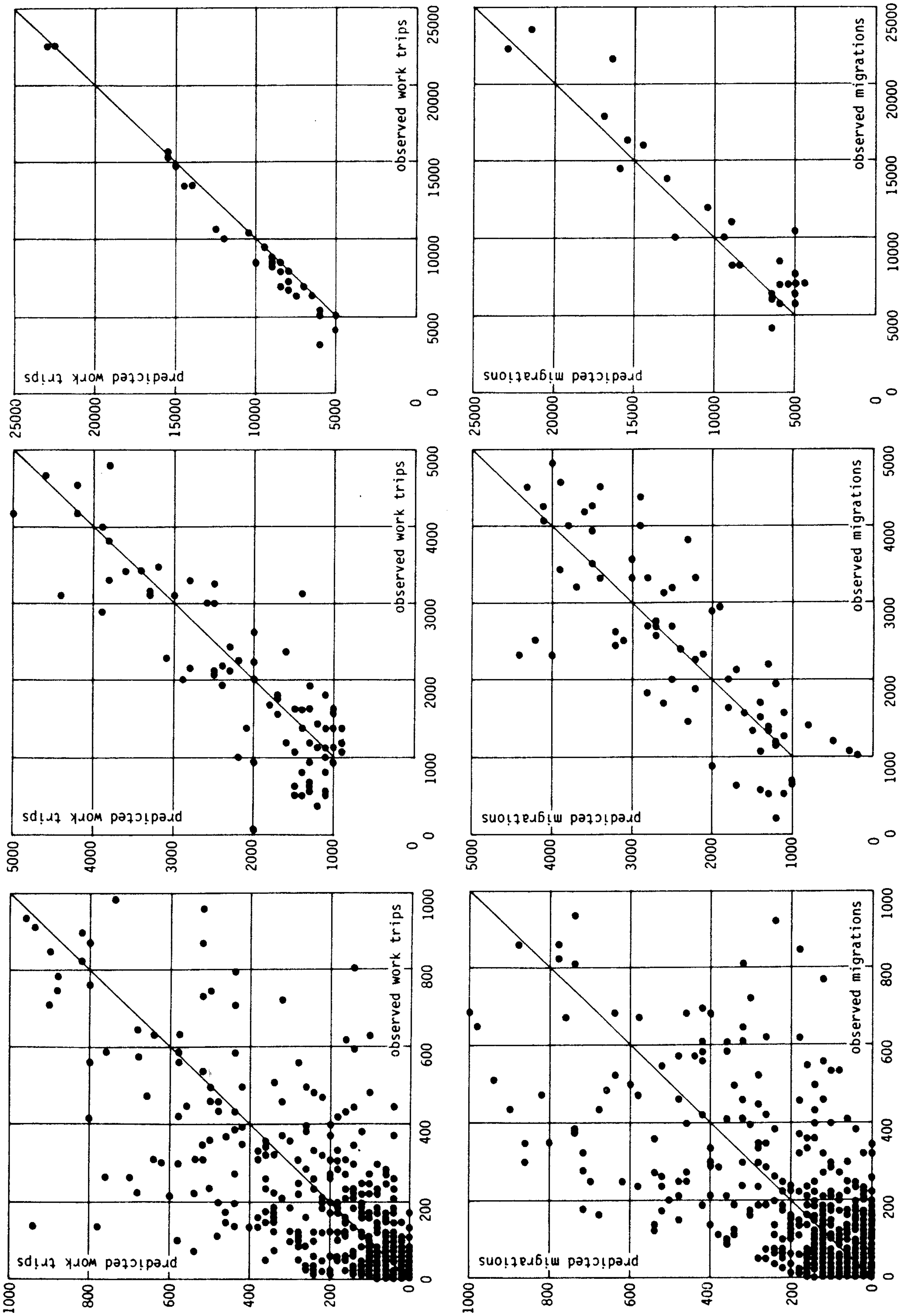

Fig. 7. Model results vs. reality: Work trip flows (top) and migration flows (bottom) by flow volume. Dortmund region, 1970-1971.

the commuting and migration flows predicted by the model. At first sight, the high coefficients of determination (r^2) for total work trips and total migrations seem to indicate a good correspondence between model and reality. However, an inspection of actual error ranges on a flow-by-flow basis reveals that only 29.1 percent of all work trips and 20.8 percent of all migration flows are predicted with an absolute error of not more than 30 percent of the observed flow volume. As this seems to be a generous error margin for a predictive model, the performance of both, the work trip model and the migration model, must be called rather disappointing.

It can also be seen from Table 2 that the error ranges of both models are closely related to the volume of flow. If work trip and migration flows are subdivided by observed flow volume into three groups, most large percentage errors are found in the low volume group. while predictive accuracy improves with increasing volume of flow. This relationship is distinctly illustrated by the scatter diagrams of Figure 7 showing actual vs. predicted flows for each of the three volume groups.

As errors associated with minor flows may be of less importance for prediction purposes, another goodness-of-fit statistic has been included in Table 2:

$$a = \frac{\sum_i \sum_j |T_{ij} - T^o_{ij}|}{\sum_i \sum_j T^o_{ij}} 100 \qquad (6)$$

is the mean absolute error in percent of mean observed flow volume, with T^o_{ij} and T_{ij} being observed and predicted flows, respectively. This statistic has been suggested by Smith & Hutchinson (1979) as being superior to the r^2-statistic as an indicator of goodness-of-fit of spatial interaction models. The mean absolute error statistic is most sensitive to errors associated with large flows, as in its formulation flows are implicitly weighed by their volume.

A discussion of the above calibration results must consider the differences in structure of the work trip and migration models.

The work trip model is a doubly constrained interaction model. Although this is still the most widely used trip distribution model in transportation planning, only a few attempts have been made to assess systematically its predictive properties. Openshaw (1976) compared several types of interaction models and found that production-attraction constrained models performed better than singly constrained models, but still produced prediction errors too large to be accepted for most practical purposes. Smith & Hutchinson (1979) calibrated doubly constrained trip distribution models for 28 Canadian census areas and achieved mean absolute errors adjusted according to equation (6) between 27.5 and 69.2 percent of mean flow volumes.

If that is the state of the art, the calibration results presented in this paper are better than average, but certainly not good enough to be used for predictions. What can be done about this? Figure 6 seems to indicate that investing more effort in refining the space deterrence functions (cf. Openshaw & Connolly 1977) will yield only marginal improvements. It seems more promising to focus attention on the production and attraction terms of the model and disaggregate travellers by attributes such as income, age, and car availability. Of course, to follow this direction would eventually lead to giving up the production-attraction constrained model altogether, as it has been done in advanced disaggregate transportation modelling.

This step has been done already in the migration model in which migrations are the result of a highly disaggregate micro simulation. Clearly, the fit of this model, as it presently exists, is even worse than that of the work trip model. However, this is not surprising, as in this model, unlike in the work trip model, no information from marginal constraints is utilized. Neither does the migration model use information about past migration flows, as do probabilistic migration models.

Instead, this model is exclusively based on causal-behavioural assumptions about the decisions of households in different situations on the housing market, dependent upon their housing status, housing needs and preferences, and income, and upon the information about housing supply and housing cost available to them. Even if in such a model the space-discounting behaviour of households is satisfactorily modelled, a multitude of preference functions concerning nonspatial aspects of migration remain to be calibrated. In the calibration of these functions statistical estimation techniques play only a minor role, not so much because of lack of data, but because of the immense difficulties of extracting quantitative preference information from existing household surveys. Therefore, many of these functions have to be determined by judgment, inferences, analogies, and careful checking of plausibility. This process of informal calibration is currently still in progress.

Subsequent work will deal with disaggregating total migration flows by household type, i.e. socio-economic group, and thus study the socio-spatial consequences of intra-regional migration in more detail. In addition, policy simulations assuming major shifts of the economic structure of the region will be performed to analyze the impacts on the housing market and the migration patterns.

In a future project, it is planned to start the model as far back as the year 1950 in order to reproduce a longer time period of urban development encompassing time phases of urban growth as well as phases of suburbanization and eventually de urbanization.

Conclusions

In this paper, a model framework has been presented in which the causal relationships between job location and migration within an urban region are explicitly modelled. A measure of locational attractiveness for migration, called migration distance, has been suggested which takes account of the present housing location of a moving household as well as of the location of the workplace of its head. This measure allows the introduction of the impact of job accessibility on the choice of a new housing location into disaggregate migration modelling. The usefulness of the approach was tested in simulation experiments conducted with data from the urban region of Dortmund. A comparison of simulated work trip and migration patterns with actual data showed that the model reproduces well the space-discounting behaviour of commuters and migrants in the region, but that there are large deviations between observed and simulated flows when compared on a flow-by-flow basis, especially with flows of lower volume.

These results suggest that further research is required in the aspatial determinants of intra-regional mobility rather than in its spatial aspects which seem to be investigated comparatively well.

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