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Towards an Integrated Spatial Dynamic Model for Amsterdam

Rima, A., Wissen, L. van and Nijkamp, P.

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TOWARDS AN INTEGRATED SPATIAL DYNAMIC MODEL FOR AMSTERDAM

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CONTRIBUTIONS TO THE METROPOLITAN STUDY:

1. Anas, A. and L.S. Duann (1983) Dynamic Forecasting of Travel Demand. Collaborative Paper, CP-83-45. International Institute for Applied Systems Analysis (IIASA), A-2361 Laxenburg, Austria.

2. Casti, J. (1983) Emergent Novelty and the Modeling of Spatial Processes. Research Report, RR-83-27. IIASA, Laxenburg, Austria.

3. Lesse, P.F. (1983) The Statistical Dynamics of Socio-Economic Systems. Collaborative Paper, CP-83-51. IIASA, Laxenburg, Austria.

4. Haag, G. and W. Weidlich (1983) An Evaluable Theory of a Class of Migration Problems. Collaborative Paper, CP-83-58. IIASA, Laxenburg, Austria.

5. Nijkamp, P. and U. Schubert (1983) Structural Change in Urban Systems. Collaborative Paper, CP-83-57. IIASA, Laxenburg, Austria.

6. Leonardi, G. (1983) Transient and Asymptotic Behavior of a Random-Utility Based Stochastic Search Process in Continous Space and Time. Working Paper, WP-83-108. IIASA, Laxenburg, Austria.

7. Fujita, M. (1984) The Spatial Growth of Tokyo Metropolitan Area. Collaborative Paper, CP-84-03. IIASA, Laxenburg, Austria.

8. Andersson, Å.E. and B. Johansson (1984) Knowledge Intensity and Product Cycles in Metropolitan Regions. Working Paper, WP-84-13. IIASA, Laxenburg, Austria.

9. Johansson, B. and P. Nijkamp (1984) Analysis of Episodes in Urban Event Histories. Working Paper, WP-84-75. IIASA, Laxenburg, Austria.

10. Wilson, A.G. (1984) Transport and the Evolution of Urban Spatial Structure. Collaborative Paper, CP-84-41. IIASA, Laxenburg, Austria.

11. Anas, A. (1984) The Combined Equilibrium of Travel Networks and Residential Location Markets. Collaborative Paper, CP-84-42. IIASA, Laxenburg, Austria.

12. Batten, D., P. Newton and J. Roy (1984) Nested Dynamics of Metropolitan Processes and Policies - Melbourne. Collaborative Paper, CP-84-47. IIASA, Laxenburg, Austria.

13. Mackett, R.L. (1984) Nested Dynamics of Metropolitan Processes and Policies - Leeds. Collaborative Paper, CP-84-48. IIASA, Laxenburg, Austria.

14. Dendrinos, D.S. and M. Sonis (1984) Variational Principles and Conservation Conditions in Volterra's Ecology and in Urban Relative Dynamics. Collaborative Paper, CP-84-49. IIASA, Laxenburg, Austria.

15. Batten, D. (1984) The Changing Economic Structure of Metropolitan Regions: A Preliminary Comparative Analysis. Collaborative Paper, CP-84-50. IIASA, Laxenburg, Austria.

16. Fischer, M.M. and G. Maier (1984) Spatial Discrete Choice and Labor Supply Modelling: Some Alternative Probability Choice Structures. Collaborative Paper, CP-84-51. IIASA, Laxenburg, Austria

17. Törnqvist, G. (1984) Contact Potentials in the European System. Collaborative Paper, CP-84-55. IIASA, Laxenburg, Austria.

18. Rima, Annemarie, Leo van Wissen and Peter Nijkamp (1985) Towards an Integrated Dynamic Model for Amsterdam. Collaborative Paper, CP-85-5. IIASA, Laxenburg, Austria

FOREWORD

The project "Nested Dynamics of Metropolitan Processes and Policies" started as a collaborative study in 1983. The Series of contributions is a means of conveying information between the collaborators in the network of the project.

This report gives an overview of the structure of a dynamic model built for the Amsterdam Metropolitan Region. The study concentrates on problems of analyzing and predicting the developments in the housing market to which demographic changes are explicitly related in a suggested model.

Åke E. Andersson
Professor of Economics
Leader
Regional Issues Project

February 1985

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1. INTRODUCTION

In this paper a set of foundation stones for an integrated spatial dynamic model for Amsterdam will be discussed. This paper draws on a series of research efforts undertaken in order to provide more adequate insight into the complex dynamics of Amsterdam: prior to building this model, we have made an international survey of existing dynamic models describing structural change, a long-term analysis of the development of Amsterdam since 1950 based on a test of relevant growth hypotheses and a first inventory of available time series data on relevant variables for Amsterdam. Here we will not report on this preparatory work. The interested reader is referred to Nijkamp et al.(10), Mouwen and Nijkamp (8) and Van Wissen et al. (13). Although the most important characteristics of the whole model will be discussed in this paper, the main emphasis will be placed on the first submodel under construction: the housing and population model.

The organization of the paper is as follows. The general framework of the integrated model for Amsterdam will be discussed in section 2. Section 3 deals with the development of Amsterdam aligned to the population and housing dynamics. Also the implications of this development since 1950 for the population and housing submodel are treated in this section. Section 4 is devoted to the analysis and simulation of necessary data, while section 5 deals with the description of the model itself. This paper ends with some concluding remarks in section 6.

2. A DYNAMIC MODEL FOR AMSTERDAM

In this section we will provide a first design of the abovementioned dynamic model for Amsterdam. This model should comply with the following conditions:

- It is dynamic; it should serve to describe and analyse the development of Amsterdam from 1950 onwards.
- It is complete; different subsystems such as the housing market, labour market and infrastructure as well as their mutual interrelationships will be taken into account as detailed as possible, given the time horizon of the project.
- It is zonal and covers both the city of Amsterdam (10 zones) and the agglomeration of Amsterdam (8 zones excluding the city). (See figure 1 and 2 for maps of the city of Amsterdam and its agglomeration.).
- It is micro-based; it starts at a disaggregate level in order to incorporate explicit assumptions concerning household and individual behaviour. The relations between the micro, meso and macro level are dealt with by means of (dis)aggregation procedures.
- It is realistic; given the data available, a combination of estimation and simulation techniques based upon empirical data (constrained simulation) will be used to explain and forecast the development of Amsterdam (see section 4).

The latter element of this sequence is regarded by us as very important, as it is our aim to construct a realistic model for Amsterdam with the help of (a blend of) existing mathematical techniques (nested logit, least squares) and existing dynamic model concepts. In our view, the current urban dynamic models are theoretically well developed, but they exhibit many limitations, so that they fail in case of a detailed empirical application, especially because frequently a great many irrealistic assumptions have to be made for an empirical analysis of one city or agglomeration. Consequently, the results of such a model can hardly be used for planning and policy strategies of a specific area.

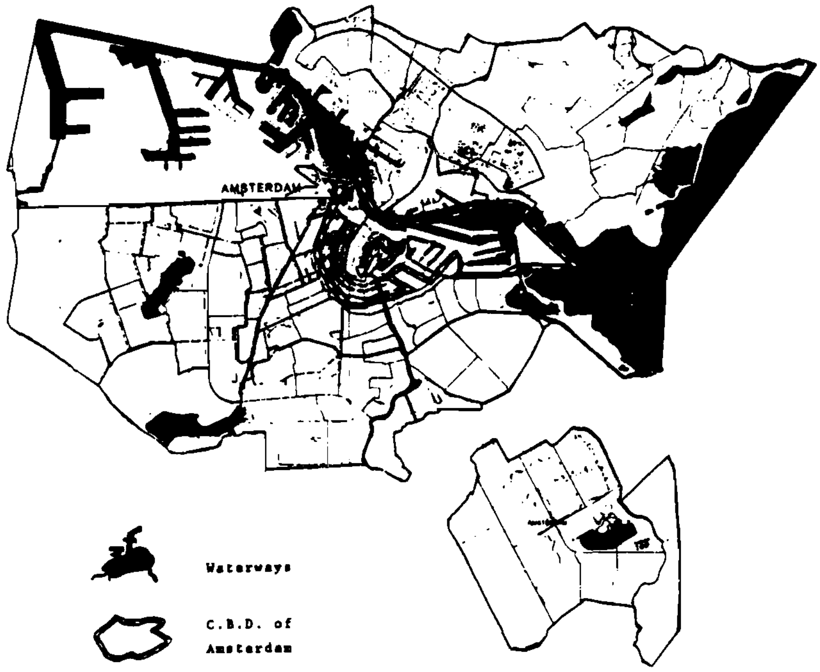

Figure 1. The city of Amsterdam and its C.B.D.

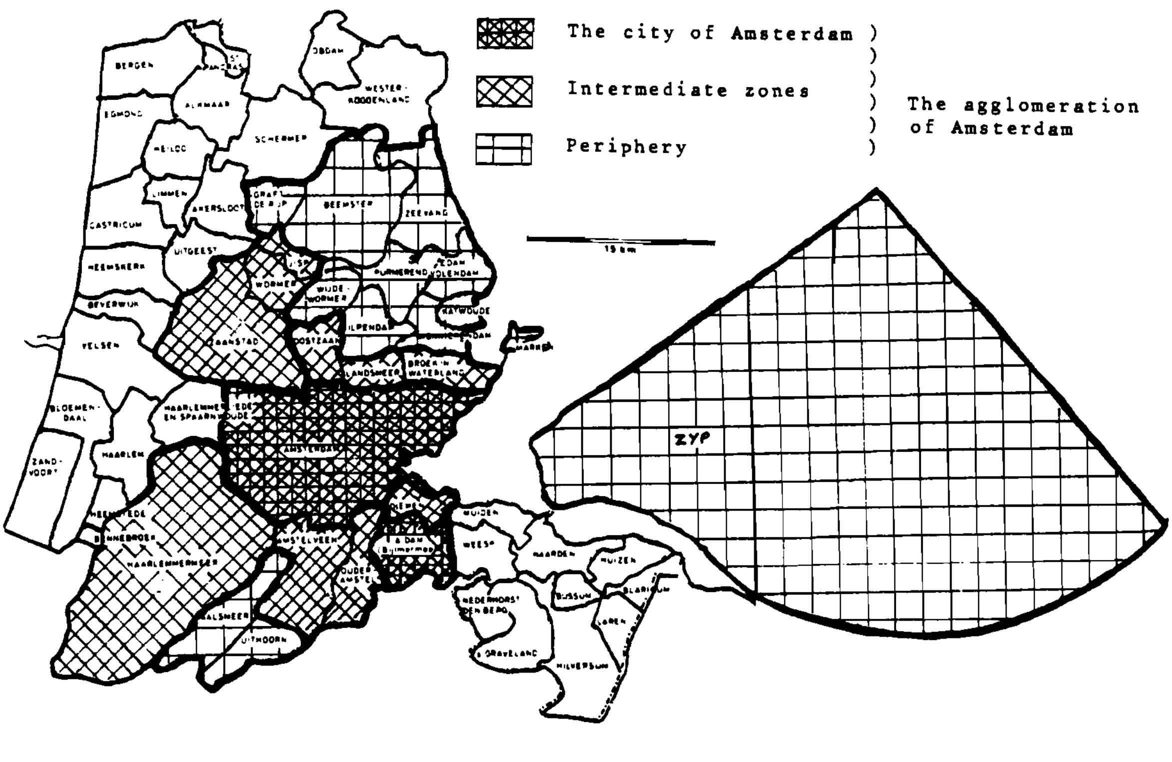

Figure 2. The agglomeration of Amsterdam.

The general structure of the dynamic model for Amsterdam is depicted in figure 3. In this configuration 5 subsystems can be distinguished, viz. (1) population, (2) housing, (3) employment, (4) (economic) infrastructure and (5) transportation.
It has to be emphasized that each subsystem is a dynamic subsystem, describing the trajectory of the relevant elements over time for each zone of the urban system. Clearly, these subsystems may exhibit different time trajectories (a so-called differential dynamics). Each of these subsystems is described in more detail below.

Within this general structure several strong interrelationships can be identified. The population and housing sector interacts within a housing market framework. In particular, an extremely restricted and institutionalized housing market situation is typical of the Amsterdam situation. Clearly, the so-called market structure represents in this case a complex set of multiple interactions between a restricted demand and supply side, so that the modeling of this process is a difficult task.
Also another demand and supply relationship is relevant within the urban context: economic activities exert a demand for space, work places and other infrastructure facilities within the city. This infrastructure may be available or supplied at different locations and in various rates by the local government, private developers and/or physical stock owners. Here too, the market is extremely restricted, so that the price mechanism is not the only equilibrating factor.

As a consequence of the mechanism of these two markets, households and enterprises are located at specific places in the city. Of course, these locational decisions are interdependent. The choice of dwelling and/or workplace is determined, among other things, by cost and time saving principles from the viewpoint of both the household (minimizing commuting

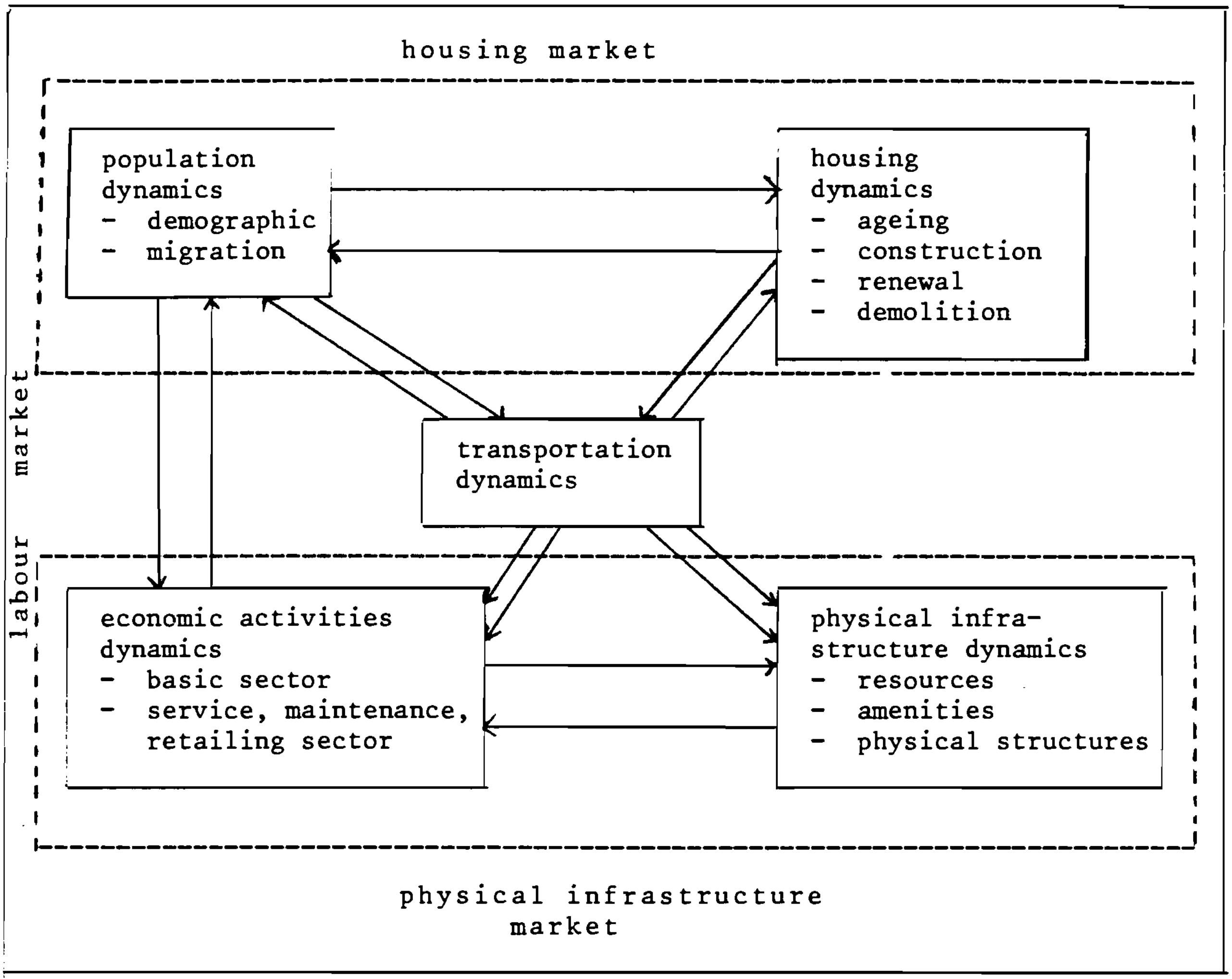

Figure 3. General structure of the dynamic model for Amsterdam.

time, e.g.) and the firm (optimal accessibility to the local or regional market, e.g.). The transportation sector facilitates these transportation flows, and is thus an important factor in creating the urban structure (cf. Nijkamp et al., (10) ; Klaassen et al. (6)).

3. POPULATION AND HOUSING DYNAMICS IN AMSTERDAM

3.1. Population Developments

Developments in population take place as the result of demographic changes (birth, death, ageing,etc.) and of population movements. Both elements have had a strong impact on the population of Amsterdam.

In particular the following remarks can be made concerning the development of Amsterdam since World War II (see also Mouwen and Nijkamp, (8)):

- After 1945 a marriage and birth 'boom' took place that led in the fifties to a considerable increase in the number of families with children. As a result total population increased until 1958.
- In the sixties a great many social and cultural changes took place that affected demographic developments, particularly in Amsterdam. A diversity of new household types emerged (mostly of a smaller size) and as a result the average number of persons per household decreased drastically.
- During the fifties, a large number of households who worked in Amsterdam but lived elsewhere (e.g., in peripheral areas), tried to migrate to the city. This process came to an end in the sixties, when suburban locations offered better living opportunities.
- Not only people from outside Amsterdam moved to suburban locations; also in the sixties a large outmigration stream of inhabitants of Amsterdam took place. This was caused partly by the housing market situation in Amsterdam, partly by physical planning policies, and partly by changing housing preferences.
- Due to urban renewal activities, which started slowly in the seventies and continued through the eighties - even at a much larger scale - the phenomenon of forced migration emerged.
- The negative implications of the outmigration of mainly young and more affluent families became apparent after 1970. The selectivity of this process led to a concentration of less wealthy and small households in older residential areas of Amsterdam.
- After 1970, a growing number of people from Surinam and from Mediterranean countries inmigrated to Amsterdam and were concen-

trated in some specific zonal segments of the local housing market.

The quantitative development of the population of Amsterdam since 1950 can be seen in figure 4.

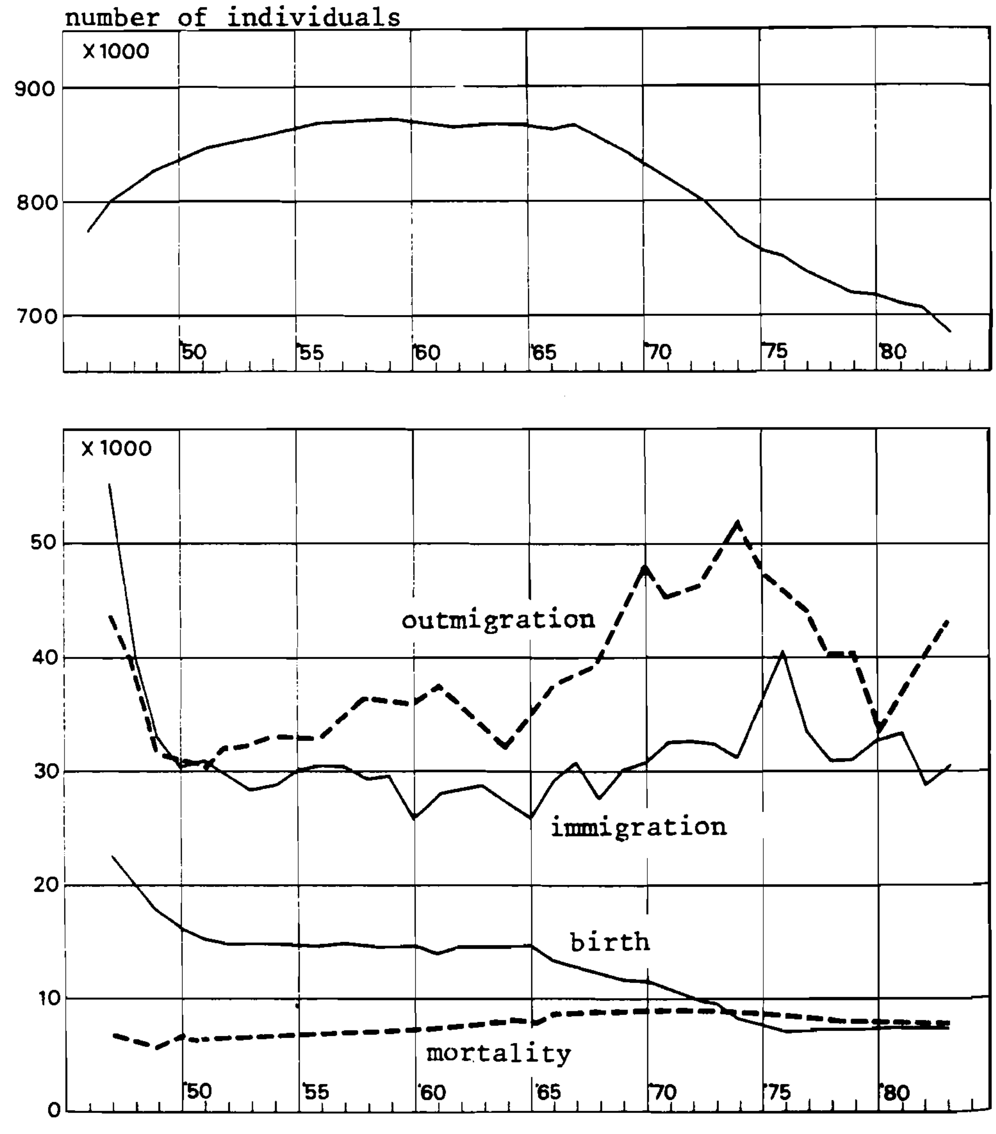

Figure 4. The development of the population of Amsterdam, and its demographic components, 1947-1982.

3.2. Housing Developments

Within the housing sector the following developments after 1945 can be observed:

- The period after 1945 has been characterized by a tremendous housing shortage for a long time. As a result, the government tried to control both housing construction and the allocation of household to dwellings.
- Before 1950, there was hardly any building industry, due to a shortage of building materials. After 1950, the new residential areas started to grow. They were already planned in the famous General Master Plan for Amsterdam in 1933. However, since there was only one actor that controlled the building process, the result was highly uniform.
- Despite the emergence of these residential areas, the supply was still lagging behind the demand for dwellings. After 1960 a new solution was found: planned decentralization of urban population. Thus, the housing market extended beyond the city boundaries, first in neighbouring areas and later in more distant locations.
- At the same time, the Amsterdan area grew by annexation of large development areas. Here, mainly high-rise buildings emerged in the seventies which were rather expensive and less attractive.
- Within the existing housing stock important developments took place. In 1960 it was recognized that within a very short time a large part of the older (19th century-)housing stock needed considerable maintenance and improvement investments. Rents were purposely kept low however, so that many landlords did not consider it profitable to take care of maintenance. Private renewal activities occurred only within the expensive housing stock. In the

seventies, large urban renewal plans were developed by the municipality of Amsterdam.

- Housing supply appeared to react slowly to housing demand. In the seventies, it was recognized that urban residents had a different household composition. It was also recognized that certain household groups preferred a central location in the city, so that more effort was put in higher density urban renewal schemes with a variety of housing types. The concept of the compact city emerged at the end of the seventies.

Figure 5 visualises the development of the housing stock in Amsterdam during the last decades. Changing household compositions give rise to a fast decreasing dwelling occupation rate since World War II (see figure 6.). As a consequence of these last two developments one may expect a tendency that the problem of housing shortage for the housing market as a whole will diminish in a few years. The shortage on the submarket of two- and three-room dwellings, however, will continue.

In our view, the housing market development in Amsterdam may be regarded as the central intra-urban process since 1950 in Amsterdam, and also the key factor in explaining the dynamics in other subsystems. In recent years, housing policy is gradually shifting from quantitative towards qualitative aspects of the housing market, and housing rehabilitation becomes more and more important in Amsterdam.

In designing a model for the complex housing market, the transportation sector and the economic activities sector will be treated as exogenous in the initial stage of model development. In a later phase the model will be extended to incorporate these subsystems.

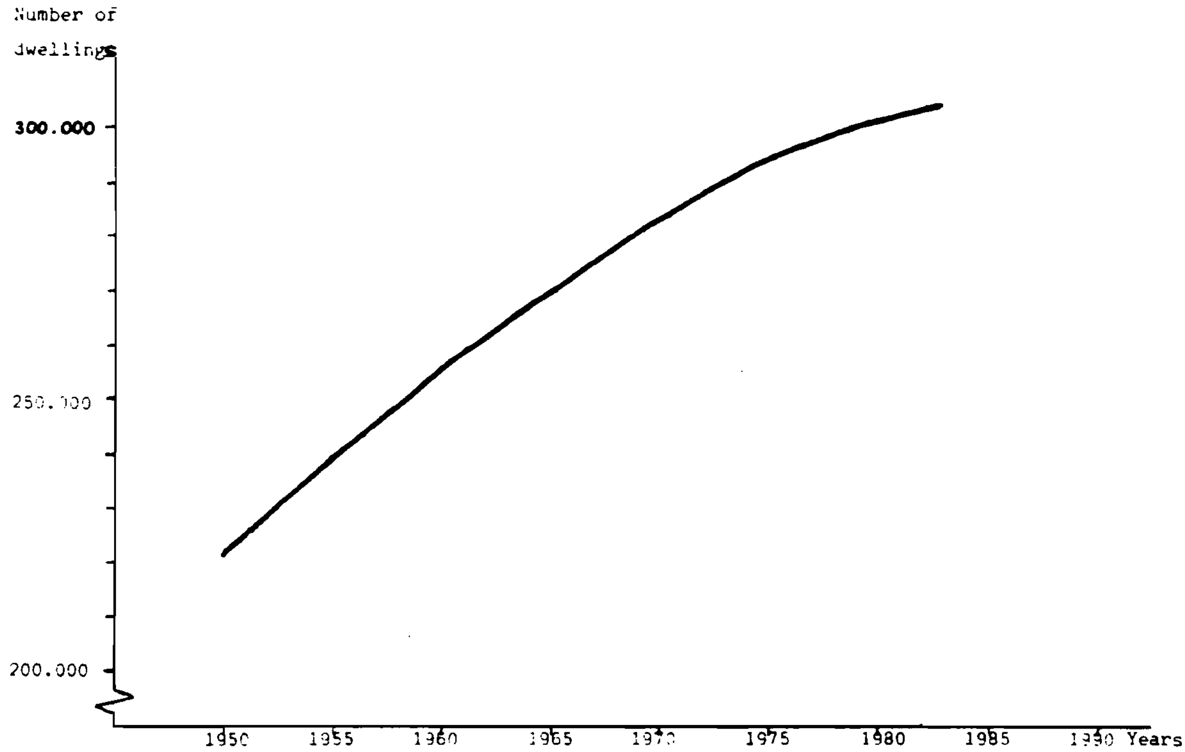

Figure 5. The development of the housing stock in Amsterdam, 1950-1983.

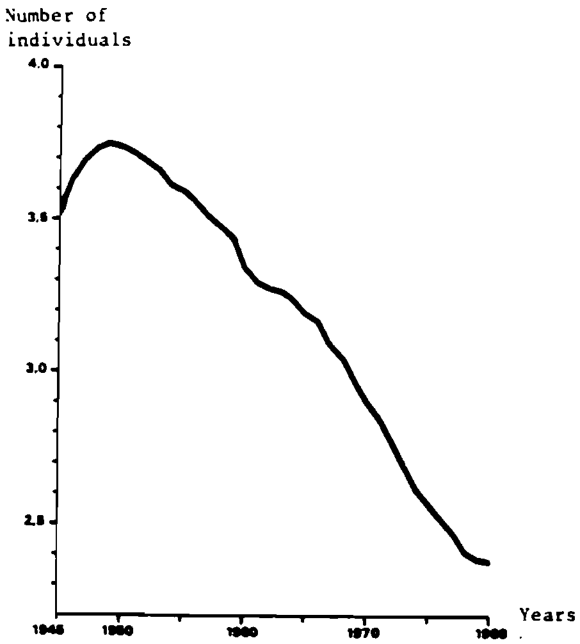

Figure 6. The average dwelling occupation in Amsterdam, 1945-1980.

3.3. Housing Market Characteristics

As a result of the enormous excess demand, the government has considerably restricted the free functioning of the housing market. These restrictions apply to that part of the housing market that is defined as the social distribution sector. Initially, it was a part of the whole housing stock, later only the less expensive dwellings were included. These restrictions apply mainly to special groups of people operating on the market and to the allocation of dwellings to households (i.e., there is a strong relationship between household size and dwelling size):

- Not only is the allocation restricted, but also is the rent fixed by the government. On the non-restricted rent market, the annual rate of change of rent is bounded within certain limits. The only free market segment, in which price plays a major market clearing role, is the non-restricted buyer-segment. This is only a small portion of the housing sector.
- Despite these restrictions, households are still free to choose on what part of the housing market they will operate, and in what location. They can refuse to accept a dwelling offered to them by the government and can search for an appropriate housing unit themselves within certain constraints. Thus, there is still a relationship between housing preferences and housing choice.
- As a result of restrictions and excess demand, primarily in the lower quality housing sector, two phenomena became important elements within the housing system. First, the 'black market' has emerged, as government control became more important although the number of dwellings involved increased considerably in the seventies. Unfortunately, data on developments in the black market

are hardly available. In addition, another phenomenon could be observed in the seventies: the non-official (sometimes illegal) occupation of vacant dwellings. This 'squatter system' was later to some extent accepted by the local government as a temporary means to fulfill the housing needs of specific groups (e.g., students, unemployed young people).

3.4. Implications for Modeling the Housing Market

- Demographic developments and migration are distinct, but interrelated phenomena. Therefore, it is plausible to model these processes separately in two interlinked submodels. In the demographic submodel changes in the household composition within every zone and time period are modeled, after a clustering of individuals into households. In section 5 this concept of clustering individuals into households and the construction of the transition matrix of household classes will be considered in more detail. So as a starting point for the migration-submodel the household is defined as the basic decision unit, and its individual behaviour is modeled - at least theoretically - at a micro level.
- The housing dynamics is treated within the housing submodel. Addition of new dwellings and subtraction of old dwellings is controlled by the local government. Initially, these processes are treated as exogenous.

  Another dynamic element is the development within the existing housing stock. Although these processes are partially the result of investment decisions of individual landlords and developers, this element is initially treated as a simple probabilistic ageing submodel.

- The demographic submodel provides a picture of the changing household composition within each zone. Household types have to be defined on the basis of size,age, composition and preferably income and job location.
- For the migration submodel, a utility framework is the appropriate basis for the model design. In this framework, the household is assumed to be the basic decision unit, while decisions are assumed to be taken on the basis of a comparison of utilities of a finite set of alternatives. Not all choice alternatives are open to every household. A priori a specific choice set is defined separately for every household type.
- Another set of restrictions may come about, viz. when individual demand is aggregated. Due to insufficient supply, not all (sometimes most) households cannot obtain their optimal preferred dwelling, and have to reevaluate their preferred decision.
- Despite these restrictions, each household is still faced with a large number of alternatives. However, it can be assumed that not all alternatives are treated simultaneously, but that there is a nested choice structure with the following choice moments: (a) the preferred choice to migrate (b) given this choice, the preferred choice of location, and (c) given (a) and (b), the preferred choice of housing type.
- The market clearing process is governed by many constraints. There are a priori constraints, and through aggregation, a lot of possible alternatives are no longer available to most of the potential migrants. Thus, the model has to take into account two preferred location decisions, and the learning or experience of

the household from unsuccessful tries. Potential migrants may then choose to stay in their current dwelling, if they cannot find a reasonable alternative. The proposed migration model has this feedback mechanism.

- On the basis of the development of Amsterdam, we assume that the dynamics on the housing market occurs mainly as a result of life cycle patterns and housing preference changes.
  Other factors, particularly job location, play a less important role within intra-urban relocation processes, though they may be significant at an inter-urban scale.
- Within parts of the housing market, there is some adjustment of prices to the market situation. These adjustments take place after a certain time lag.
- Clearly, the supply side adjusts itself to some extent to demand. Due to an unfeasible policy structure, and construction time delays, the time lag is even longer than the pricing adjustments.
- The development of the transportation system and of the economic activities have had a significant impact on the population and housing dynamics. These influences have not taken the form of constraints, however (possibly the only exception being the labour shortage in the building industry in the fifties). Thus, initially, we will treat these factors as exogenous variables in the utility functions of households.
- On the contrary, in the economic activities model, there are some thresholds regarding the population level (e.g. labour market requirements, threshold values for entering a market). Hence, development of economic activities is conditional on population dynamics.

4. A METHOD FOR ANALYSING AND SIMULATING DATA

The data requirements of a dynamic zonal model are considerable. In collecting these data a number of problems may arise such as:

- Incompleteness of data for some periods. Often, only univariate distributions are available, and sometimes only at an aggregated level, while multivariate distributions at a disaggregate level (by zone and by population/housing etc. sector) are needed.
- Changes in definitions of basic entities over time, and between data sources.
- Errors in basic statistics, especially in figures from the precomputerized time period.
- Time-consuming multi-period data collection. If the number of time periods is large, the effort to collect all necessary data may be escessively high.
- Confidentiality of data. Even if data at a detailed level are existent and ready for use (tape, disk, e.g.), they may not be available, due to confidentiality problems, non-cooperation of government institutions, etc.

As pointed out in section 2, our aim is to design a dynamic model that is as realistic and empirical as possible. Thus, we aim at building a bridge between purely theoretical modeling efforts and purely descriptive empirical work in the field of urban economic research.

Despite the fact that a lot of information on Amsterdam is missing, the amount of data that is available and can be used is still considerable. Existing data sources include both published and unpublished figures from the national and city bureaus of statistics,

and samples taken for various purposes by planning agencies, research centres, etc.
In view of these data, a method that integrates these existing data sources into a dynamic dataset is needed. This set is both comprehensive (in that it contains the information needed for the estimation of our model) and reliable (being in accordance with our prior knowledge). Thus, the method should first be able to explore, by means of a thorough statistical analysis, the information available in these data, and second, use this information to simulate the missing data.

This method rests upon the assumption that there is a structure in the known data that can be explored using appropriate statistical techniques. By structure we mean that a coherent set of all basic ('key')variables and relationships exists within the dataset. Many variables are categorical, and the relationships between variables do not necessarily have to be linear. Therefore, we have to rely on a number of categorical and non-linear statistical techniques to explore this structure (see below).

We do not claim that a model that is based on this partly simulated data is able to describe in detail and in precise quantitative form the metropolitan development over the whole period. We do claim, however, that if we are able to detect the basic structure in the known data, the model built upon this structure is able to highlight the role of certain key variables and relationships within the urban system. Moreover, as the data are getting more detailed in recent years, the model is getting a more firm basis and should be able to give more precise quantitative and predictive answers.

The required data for the dynamic model proposed here takes the form of a multi-dimensional matrix, with dimensions time (t), zone (i) and sectors (s). For different submodels, different sectors are distinguished. Thus, for the demographic model there are household sectors, and for the housing market model both household and housing sectors can be distinguished. In the analysis of this matrix a top-down approach is applied, in which first the structure at the metropolitan level, then at the zonal level and next at the sectoral level is studied. Figure 7 presents the necessary steps in the statistical analysis.

At the metropolitan level we deal with variables $X_{1t},\dots,X_{kt}$ for a number of time periods $t=1,\dots,T$ (say, 30 years).
X_{11} might be the total population in the metropolitan area in year 1, and X_{21} might be the total housing stock in year 1 .
In univariate analyses the development of these variables over time can be studied. $X_{11}\,X_{21}$ is the interaction between two variables (say, population and housing stock) and the development of this interaction over time can also be analysed.
An important element of these analyses is the testing of the hypothesis of stability of relationships between variables over time.
In summary, at the metropolitan level the following analyses will be applied (the numbers of the arcs in the figure correspond to the number aligned to the analysis in the text):

1. univariate time series analysis for each variable;
2. multivariate time series analysis, i.e. the evolution of relationships between variables.

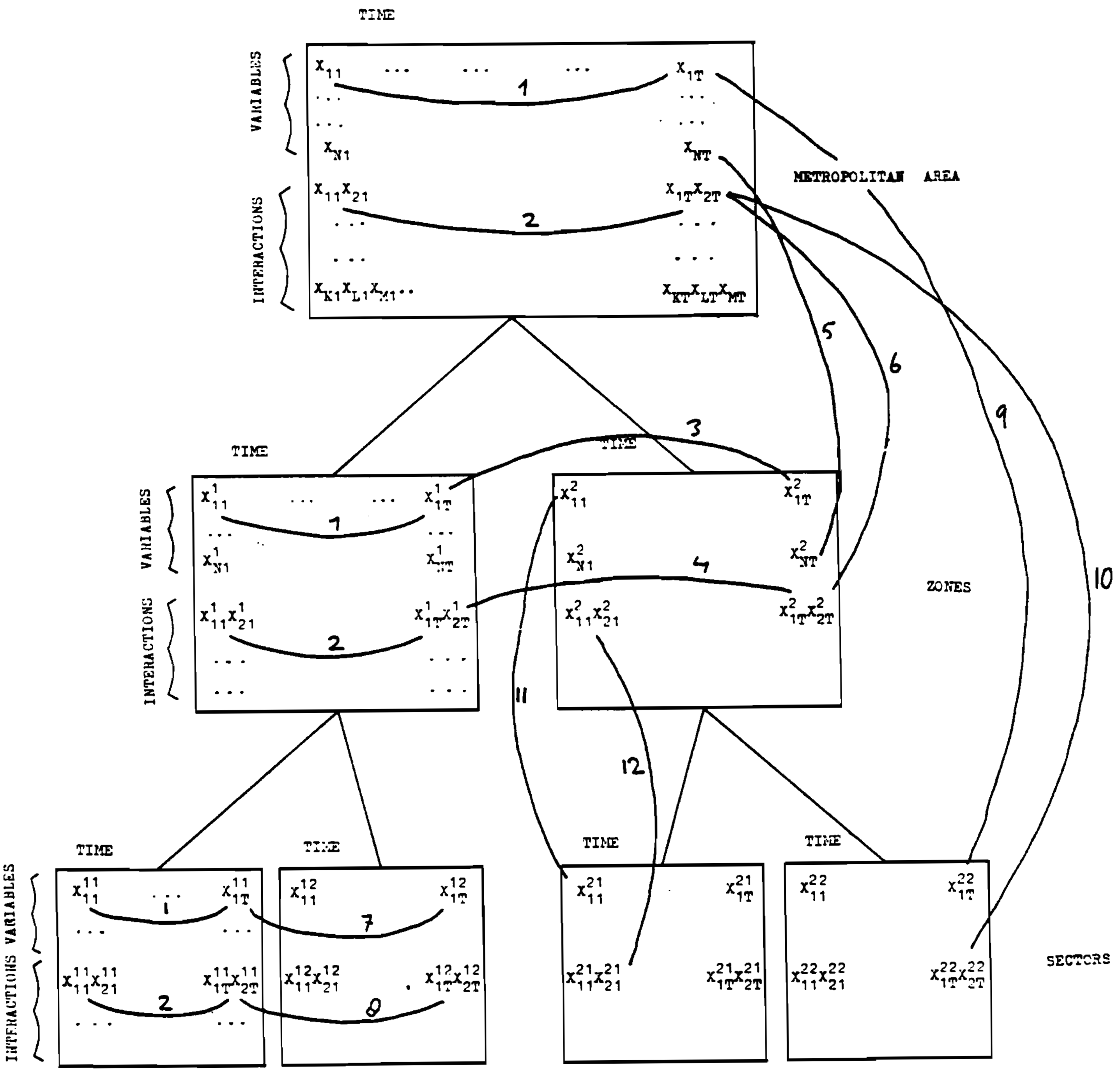

Figure 7. Nested zonal-sectoral data structure of a metropolitan system (the arcs denote analyses to be conducted; see text).

In the next step a zonal disaggregation is performed which separates each variable x_{kt} into variables x^i_{kt}, (i=1,...,I, is a zone index). A time series analysis at the zonal level can be carried out, in a way analogous to that at the metropolitan level (development of population in zone i). In addition, the following analyses have to be undertaken:

3. cross-section analysis of x^i_{kt} over the zones in a number of selected time periods;
4. cross-section analysis of interactions between variables over the zones in a number of selected time periods;
5. (in connection with 3) a test on the effect of zonal disaggregation for univariate distributions;
6. a test on the effect of zonal disaggregation for multivariate distributions. Both 5 and 6 are very important prerequisites for the data simulation process.

In the third step, the sectoral dimension is added (e.g., households divided by life cycle class). In this step every variable x^i_{kt} (e.g. total number of households in time t in zone i) is further disaggregated by sector s (s=1,...,S is a sector index). This analysis proceeds in the same way as in the second step, although we now have a disaggregation at both the metropolis-sector level and the zone-sector level.

This exploration of the basic structure of the data is necessary in order to make reliable estimates of missing data. In many cases, we only have marginal distributions of variables, except for some time periods (hopefully reasonably spread over the whole period). If we can conclude on the basis of the analysis that the relationship between two or more variables is stable, we can estimate the joint distribution for other years.

Another result may be that some relationships are constant over space, and/or over sectors. This also could help in simplifying the theoretical model toward an operational form.

The techniques used for these analyses include:

- Generalized linear modeling (GLM). This is a class of models comprising inter alia linear regression, analysis of variance, contingency table analysis, bivariate logit and probit etc. (see Nijkamp and Fischer (9) for a discussion).
- Analysis of variance with repeated measurements.
- Non-metric scaling techniques (e.g., non-linear principal components analysis; non linear canonical correlation analysis; see Gifi (4)).
- Minimum information techniques for estimating missing data. The equivalence between this technique and log-linear contingency table analysis is now well known (Baxter (2), Willekens (14)).

By means of contingency table analysis we might be able to explore which interactions (over space and/or time) between variables are needed in order to estimate missing data.

5. THE DEMOGRAPHIC AND MIGRATION/HOUSING MARKET SUBMODEL

5.1. The Demographic Submodel

The main feature of the demographic submodel is the computation of the matrix of transition rates (D) of households, defined by the matrix of probabilities $P_{kk'}$ of households changing from type k to type k' (k,k'=1,...,K) during one period.
The transition matrix serves as a main input for the migration/ housing market submodel (see 5.2.) in the sense that multiplication of the transition matrix D with the occupancy matrix H in one period gives the occupancy matrix in the following period before migration (see figure 8).

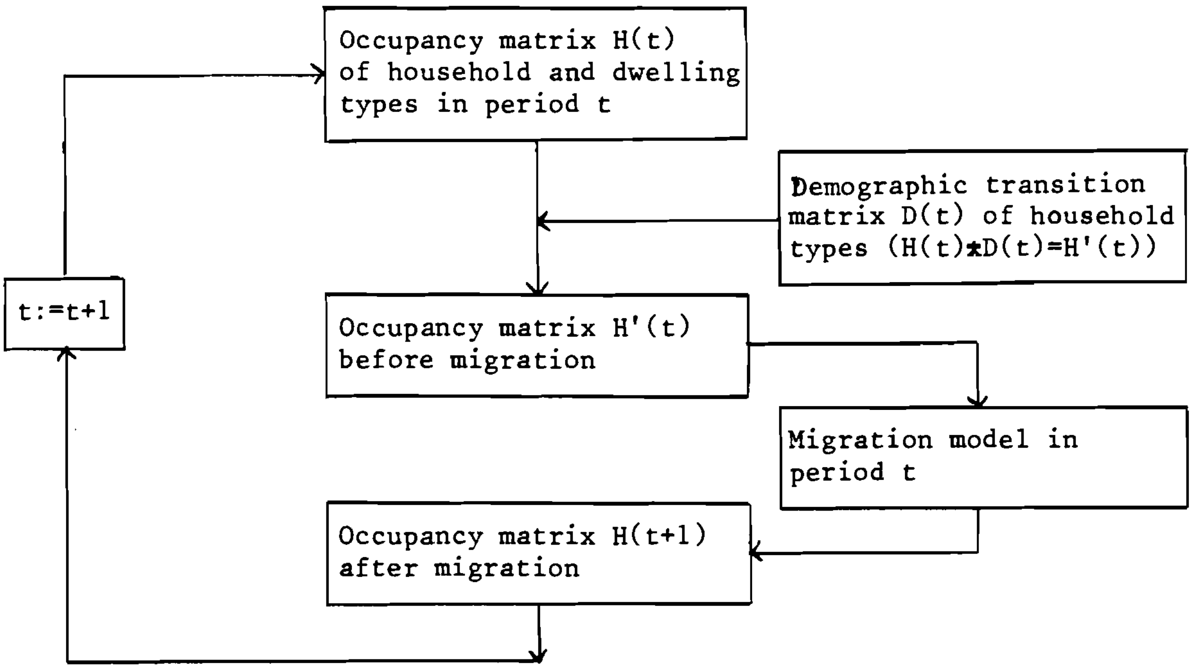

Figure 8. Connection between the demographic and the migration/ housing market submodel.

The population of each zone is classified into a number of household types (K), distinguished by

- age of head
- size
- income class.

Of course other types of classifications are possible, but we prefer to start our modeling efforts as simple as possible and refine the model later on if necessary.

The probabilities $P_{kk'}$ $(k,k'=1,\ldots,K)$ are influenced by individual-based events, such as:

- ageing
- death
- birth
- joining (e.g. marriage)
- splitting (e.g. divorce)
- children starting new households.

For multiplicational reason all these events are assumed to occur independently, but of course the probabilities of these events will differ between household types and zones.
Combinations of these probabilities will establish the transition matrix of households.

The event probabilities and the resulting transition rates will be updated every time period as they change over time.
In the validation part of our modeling efforts we will try to match the model outcomes with reality to a maximum extent and at the most disaggregated level. We will not discuss the validation procedures here, but will return to this in detail when reaching that modeling stage.

5.2. The Migration/Housing Market Submodel

In the demographic submodel, households have exhibited changes, and some of these changes involve a re-evaluation of the current housing situation (e.g. birth of a child, divorce, marriage). In the migration/housing market submodel these residential changes are modeled. The basis for this model is the following occupancy matrix H .

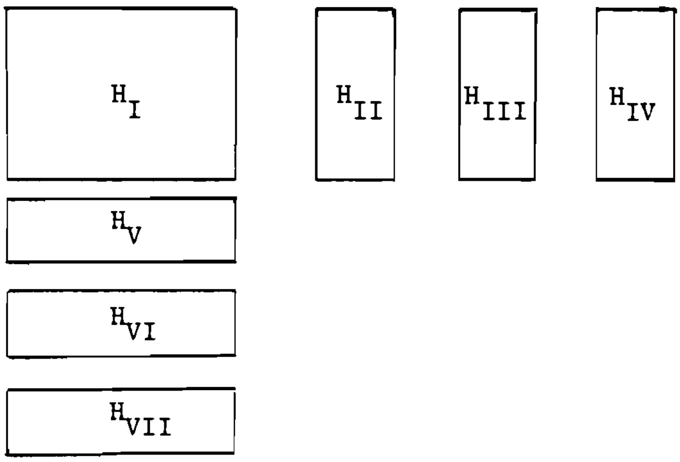

Figure 9. Occupancy matrix H of households by dwellings (for every zone and time period).

This matrix describes for every zone the allocation of households of type k (1,...,K) to dwelling types l (1,...,L) . The submatrix $H_I = \{h_{kl}\}$ describes the existing households at the beginning of period t and their dwelling types. In addition to this submatrix there are three rows and three columns: H_{II} gives the number of households of type k that start in period t . H_{III} contains households who currently have no house in period t (forced migration). Vector H_{IV} is external inmigration from outside the metropolitan area into zone i , and is exogenous to the model. Row H_V gives the number of households by housing type who existed in the beginning of the period, but no longer exist at the end of the period. Row H_{VI} contains the number of vacancies by housing type at the beginning of the period, including the new constructed houses, and H_{VII} contains households who migrate outside the metropolitan area.

Clearly, H_{II-IV} represent households without a dwelling, and H_{V-VII} represent dwellings without households (cf. Wegener (11)). In addition to households in the H_{II-IV} part of the matrix, who have to find a dwelling somewhere, a part of the H_I matrix considers a move, but can evaluate different alternatives, including a non-move. This decision process is modeled in a logit framework. However, we have to distinguish between the preferred decision and the actual choice. As pointed out before, this decision process is highly constrained. In the decision to consider a move, elements of possible alternatives are taken into account (an alternative is defined as housing type l' in zone i').

Choice of housing type is taken conditional on zone choice, and choice of zone conditional on the decision to move.
This nested structure can be treated within a nested logit form. Each decision level is described in detail below in the demand-side subsection. Next, the supply-side is treated briefly in a separate subsection.

MODELING THE DEMAND SIDE OF THE HOUSING MARKET

Choice of Dwelling Type l

Consider a household type k living in zone i in a house type l , who prefers to move to another dwelling, in the same or another zone. Conditional on zone choice there are a number of possible housing types 1' . The total choice set depends on zone i' chosen (not every zone has all possible housing types) and on household characteristics (due to market restrictions; not every choice is possible for all households).

Housing type 1 has a number of important characteristics with respect to housing preferences:

1. size of dwelling: 1, 2, 3, 4, 5 + rooms (WGR_1)
2. price: 4 categories (WPR_1)
3. quality: 3 categories (WQA_1)
4. single or multi family unit: 2 categories (WEM_1)
5. private-public sector : 2 categories ($WRES_1$)
6. tenure status: 2 categories (WEG_1) .

With these 6 dimensions, a total number of 480 distinct housing segments can be defined, and it is highly unlikely that a household will take all alternatives into account simultaneously. However, the number of alternatives is reduced by:

a. Constraints within the distribution system (see section 3.3.).
b. Choice of dwelling type is conditional on zone choice, and within one zone usually only a subset of all possible housing types can be found.
c. Suitable aggregation of certain housing types. For instance, very expensive dwellings could be treated as one category, disregarding all other dimensions. This is however largely an empirical matter and belongs therefore to the analysis stage reported in section 4. For the ease of presentation we will assume that the dwelling type decision is taken entirely simultaneously (and conditional on household type and zone choice).
   Alternative forms (i.e. block recursive structure, see Hensher and

Johnson (5); Ben-Akiva and Lerman (3)) are possible too, and sensitivity analyses concerning this point should be conducted.

Within every submarket we assume that all individual dwellings are completely homogeneous with respect to dwelling attributes and consequently have the same utility level (because of aggregation, individual dwelling utilities cannot be observed, see Anas (1), p. 136). Now, let N_l be the number of dwellings within submarket l at the beginning of the period, then an inclusive value can be defined for the expected maximum utility H_l of all dwellings within the submarket

$$H_l = \ln N_l$$

In addition to variables related to dwelling type, a number of explanatory household variables are important in relation to dwellings:

1. household income ($HINC_k$)
2. household size (HGR_k) .

Finally, it is assumed that the household has some knowledge concerning the housing market situation and that it takes into account the perceived chance of finding a dwelling of a type l , given aggregate demand and aggregate supply. This factor is denoted by WT_l and is explained in the market clearing subsection.

Now, we can specify a utility function for dwelling type l in zone i for a household k:

$$U^D_{kl} = U^A \left\{ (WGR_l - HGR_k),\ (WPR_l / HINC_k),\ (WQA_l / WPR_l),\ WEM_l,\ WRES_l,\ WEG_l,\ WT_l \right\} + U^B \left\{ \ln N_l \right\}$$

in which WGR-HGR is the dwelling size related to household size, WPR/HINC is the proportion of household income needed for housing in 1 , WQA/WPR is the housing quality in relation to housing price, and WEM, WRES and WEG are alternative specific dummies.
WT is expected waiting time and explained below. The utility function is separated into two parts. If we define $U^B\left\{\ln N_l\right\}$ as $\gamma \ln N_l$, we can express the probability of choosing 1 , given zone choice and household type k as:

$$P^D_{l/ik} = N_l^\gamma \exp\left\{U^D_{kl}\right\} / \sum_{l' \in A_{ik}} N_{l'}^\gamma \exp\left\{U^D_{kl' \in A_{ik}}\right\}$$

The data-requirements for calibration of this choice model are considerable, even for a cross-sectional (one period) situation. A complicating factor of this model is that not actual choices are being modeled, but housing preferences.
Surveys on housing preferences are available since the early seventies on a national scale, and the municipality of Amsterdam has done some additional research in this field.
These surveys can be taken as a starting housing-type choice model.

Choice of Zone i

The preferred choice of residential zone depends, among other things, on:

1. Characteristics of the zone (environmental qualities: ZKM_i , $i=1,\ldots,I$).
2. Information available to the potential migrant about the alternatives.
3. Spatial separation between current and preferred living zone.
   Both 2 and 3 can effectively be measured by a physical distance

measure between current and preferred living area : $D_{i'i}$.

4. Job location in relation to preferred location E_{is} .
5. The housing alternatives within the zone: L_{ik} (the subscript k is included because the choice set of houses is conditional upon household type). L_{ik} is the 'inclusive value' (McFadden (7)) in a nested logit framework, and can be defined as :

$$L_{ik} = \log \sum_{l \in A_{ik}} \exp \left\{ U^{D}_{kl} \right\}$$

This is a measure of the attractiveness of zone i for a type k-household due to the housing alternatives within the zone that are open to the household (A_{ik}).

Environmental qualities include features such as number of schools, shopping area , green areas etc. and these elements will in general have different weights for every household category.

In relocation-decisions not only the distance between current and alternative location is relevant, but also job location.

(in residential location models this is taken to be the principal location factor; for a recent example based on discrete choice theory: see Anas, (1)).

In an aggregated manner, this element can be taken into account using observed work trip flows (Wegener (12)).

The utility function with respect to the preferred zone i , for a household type k living in zone i' is

$$U^{Z}_{i/i'k} = U \left\{ ZKM_{ik} - ZKM_{i'k}),\ D_{ii'},\ E_{is}\ ,\ L_{ik} \right\}$$

and the probability of choosing zone i is:

$$P^{Z}_{i/i'k} = \exp \left\{ U^{Z}_{i/i'k} \right\} \Big/ \sum_{m} \exp \left\{ U^{Z}_{m/i'k} \right\}$$

Although with respect to choice of zone the same data-problems occur as concerning the modeling of housing types, we assume that observed aggregate flows are a reasonable representation of preferences.

Decision to Move

Clearly, the decision to move is not taken independent from the available alternatives.

In the decision process, a combined measure of all available alternatives is taken into account. Thus, the concept of a mover pool (in which the migration decision process consists of two totally separate decisions, viz. (1) the decision to move, and (2) the destination choice) is abandoned in our model.

The inclusive value $I_{i'k}$ represents the combined 'attractiveness' of possible destinations (zone/housing types -combinations for a household type k in zone i'), and is defined as:

$$I_{i'k} = \ln \sum_{m} \exp U^{Z}_{m/i'k}$$

Other elements, related to the current dwelling and household situation are also important:

1. household size related to dwelling size $(WGR_l - HGR_k)$
2. household income related to housing price $(WPR_l / HINC_k)$
3. housing quality related to housing price: (WQA_l / WPR_l)
4. tenure status (WEG_l)
5. single or multi family unit (WEM_l)
6. household income related to a moving cost factor $(HINC_l / MC_k)$.

Combining these elements, we get the utility function of moving for a household type k living in zone i' in a house type l' :

$$U^{M}_{i'kl'} = U \left\{ (HINC_k/MC_k),\ (WGR_l-HGR_k)\ (WPR_l/HINC_k,\ (WQA_l/WPR_l),\ WEG_l,\ WEM_l,\ I_{ik} \right\}$$

The probability for a household k of prefering to move is:

$$P^{M}_{i'kl'} = \exp\left\{U^{M}_{i'kl'}\right\} / 1 + \exp\left\{U^{M}_{i'kl'}\right\}$$

Observed migration decisions cannot be considered to give adequate estimation results for the model parameters in a restricted market situation, because supply has a strong influence on resulting patterns. Surveys on housing preferences should give a better estimate of the exact form of the demand side of the housing market.

HOUSING SUPPLY

At the supply side of the housing market three distinct processes are important:

- ageing of existing stock
- demolition and renewal
- supply of new houses.

Demolitions, renewal and the building of new houses are to a high degree controlled and regulated by the local government. These processes will, at least in this stage of the project, be treated as exogenous to the model. Deterioration of houses is a (non linear) function of ageing of houses, and will be included in the model in a probabilistic submodel. The housing stock is aged in every period and housing quality changes as a probabilistic function of this ageing process.

The Market Clearing Process

To simplify matters, let m denote all (i'l')-origins, and n denote all (i l)-destinations of zone-dwelling type combinations.

As a first step, aggregated demand is calculated:

$$T^{PR}_{kmn} = Pop_{mk} \cdot P^{M}_{mk} \cdot P^{ZD}_{n/mk}$$

Pop_{mk} is the total number of households type k in m , P^{M}_{mk} is the marginal probability of prefering to move, and $P^{ZD}_{n/mk}$ is the conditional part. T^{PR}_{kmn} is the total preferred migration from m to n by a household of type k.

Next, we define:

$$\sum_{km} T^{PR}_{kmn} = D^{PR}_{n}$$

as the total demand for dwellings in n , and

$$\sum_{kn} T^{PR}_{kmn} = O^{PR}_{m}$$

as the total demand for dwellings originating in m. The allocation of households to dwellings is achieved through a simple constrained fitting procedure. However, within one time period a number of iterations take place, in order to simulate a simplified vacancy chain process. Every outmigration has a certain probability $q^{(0)}_{m}$ (indexed by outmigration zone and iteration) of having a vacant dwelling being put on the market.

Thus O^{PR}_{m} and D^{PR}_{m} are linked, within each time period.

If $S^{(0)}_{n}$ is the total number of vacancies at the beginning of the time period (existing vacancies at the end of the last period plus new constructed dwellings in the new time period), and $D^{PR(0)}_{n}$ is total demand, we can define:

$$D_n^{(0)} = \min (D_n^{PR(0)} , S_n^{(0)})$$

as the total number of households that will actually move to n in the first iteration. Thus, we have a constraint of the form:

$$\sum_{km} T_{kmn}^{(0)} = S_n^{(0)} , \text{ if } S_n^{(0)} < D_n^{PR(0)}$$

This constraint leads to the model:

$$T_{kmn}^{(0)} = O_{km}^{PR(0)} \cdot P_{n/km}^{ZD} \cdot B_n^{(0)} \cdot S_n^{(0)}$$

in which $B_n^{(0)} = 1 / \sum_{km} O_{km}^{PR(0)} \cdot P_{n/km}^{ZD} = 1/D_n^{PR(0)}$

This model simply states that every potential migrant has a probability of $D_n^{(0)}/D_n^{PR(0)}$ of finding a dwelling in n .
Summation over the whole time period $(\sum_r D_n^{(r)} / \sum_r D_n^{PR(r)})$ gives a measure that is inversely related to the time one has to wait for a dwelling in n : WT_n .

If total demand is less then or equal to supply, there are no constraints and the following model results:

$$T_{kmn}^{(0)} = O_{km}^{PR(0)} \cdot P_{n/km}^{ZD}$$

The constrained model contains both an aggregate size effect, $D_n^{(0)}$, based on aggregate market conditions and a qualitative, utility based size effect, through the inclusive value N_n in the demand structure.

Before the next iteration, the following adjustments are made:

$$O_{km}^{(0)} = \sum_{n} T_{kmn}^{(0)}$$

$$S_{m}^{(1)} = S_{m}^{(0)} + q_{m}^{(0)} O_{m}^{(0)} - D_{m}^{(0)}$$

($q_{m}^{(0)}$ is the probability of leaving a vacant dwelling)

$$O_{m}^{PR(1)} = O_{m}^{PR(0)} - O_{m}^{(0)}$$

$$T = \sum_{r} T^{(r)} = \sum_{r} \sum_{kmn} T_{kmn}^{(r)}$$

The process stops, if T (the total number of migration made in one time period after successive iterations) equals the (exogenously) fixed total number of observed migrations.

6. CONCLUSIONS AND FURTHER MODEL DEVELOPMENTS

In this paper an outline has been presented of a dynamic integrated population-, migration- and housing market model for Amsterdam. If we confront the model developed so far with the characterization of the Amsterdam system and the resulting implications for modeling, the following remarks can be made:

- A consistent link has been made between the demographic model and the housing market model. Also, the demand side model of the housing market is, at least theoretically, appropriate for modeling household behaviour.

- On the other hand, the market clearing process is more complicated then represented in the model. Much more attention should be devoted to readjustments and reorientation of households as a consequence of market restrictions. This also includes 'black market'- and 'squatter-system' phenomena. The modeling of these phenomena is extremely difficult however.
- Changing housing preferences are one of the basic dynamic factors in the model. The development of these factors affects the demand structure of the housing market, and the modeling of these developments is an important future research task.

REFERENCES

(1) Anas, A. Residential Location Markets and Urban Transportation; Economic Theory, Econometrics, and Policy Analysis with Discrete Choice Models, Academic Press, New York, 1982.

(2) Baxter, M. 'Similarities in Methods of Estimating Spatial Interaction Models', Geographical Analysis, Vol. 14, no. 3, 1982, pp. 267-269.

(3) Ben-Akiva, M.E. and S.R. Lerman. 'Disaggregate Travel and Mobility Choice Models and Measures of Accessibility', in D.A. Hensher and P.R. Stopher (eds.), Behavioural Travel Modelling, Croom Helm, London, 1979.

(4) Gifi, A. 'Non-linear Statistical Analysis', University of Leiden, Dept. of Data Theory, 1982.

(5) Hensher, D.A. and L.W. Johnson. Applied Discrete Choice Modelling, Croom Helm, London, 1981.

(6) Klaassen, L.H., J.A. Bourdrez and J. Volmuller. Tranport and Reurbanisation, Gower, 1981.

(7) McFadden, D. 'Modelling the Choice of Residential Location', in A. Karlqvist et al. (eds.), Spatial Interaction Theory and Planning Models, North Holland, Amsterdam, 1978.

(8) Mouwen, A. and P. Nijkamp. 'Technology, Innovation and Dynamics of Urban Systems' Paper presented at the Conference on 'Innovation and Urban Development', Munich, May 1984.

(9) Nijkamp, P. and M.M. Fischer. 'Explanatory Discrete Spatial Data and Choice Analysis'. Paper presented at the German-Dutch Symposium on Theoretical and Quantitative Geography, Osnabruck, March 1984.

(10) Nijkamp, P., A. Rima and L.J.G. van Wissen. 'Spatial Mobility in Models for Structural Urban Dynamics', in B. Jansen, P. Nijkamp and C. Ruygrok (eds.), Transportation and Mobility in an Era of Transition, North Holland Publ. Co. Amsterdam, 1984 (forthcoming).

(11) Wegener, M. 'The Housing Market in the Dortmund Region: A Micro Simulation', in H. Voogd (ed.), Strategic Planning in a Dynamic Society, Delftsche Uitgevers Maatschappij, Delft, 1981.

(12) ——————— 'A Simulation Study of Movement in the Dortmund Housing Market', Tijdschrift voor Economische en Sociale Geografie, Vol. 74, no. 4, 1983, pp. 267-281.

(13) Wissen, L.J.G., A. Rima and P. Nijkamp. 'Amsterdam, Developments, Data Collection, Dynamic Modeling', Entry-ticket IIASA Research Project 'Nested Dynamics of Metropolitan Processes and Policies', 1984.

(14) Willekens, F. 'Entropy, Multiproportional Adjustment and Analysis of Contingency Tables', Sistemi Urbani, 2/3, 1980, pp. 171-201.