ASPECTS OF URBAN DECLINE: EXPERIMENTS WITH A MULTILEVEL ECONOMIC-DEMOGRAPHIC MODEL FOR THE DORTMUND REGION

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FOREWORD

Declining rates of national population growth, continuing differential levels of regional economic activity, and shifts in the migration patterns of people and jobs are characteristic empirical aspects of many developed countries. In some regions they have combined to bring about relative (and in some cases absolute) population decline of highly urbanized areas; in others they have brought about rapid metropolitan growth.

For his analysis of urban growth and decline in the Federal Republic of Germany, Michael Wegener presents a demoeconomic simulation model that describes patterns of spatial choice behavior in Dortmund. The three-phased development of this region is similar to that of many highly developed urban agglomerations and is therefore a representative example of urbanization, suburbanization, and deurbanization. By introducing the decision behavior of enterprises, households, and individuals, which reflect the scarcity of resources, the model is able to interpret the processes of urban growth and, most importantly, urban decline.

A list of recent publications of the Urban Change Task in IIASA's Human Settlements and Services Area appears at the end of this paper.

Andrei Rogers
Chairman
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ABSTRACT

In this paper, selected results of a multilevel dynamic simulation model of the economic and demographic development in the urban region of Dortmund, FRG, are presented. The model simulates 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.

In particular, the paper illustrates the capability of the model to capture not only urban growth processes, but also processes of urban decline. For this purpose, first the mechanisms which control spatial growth, decline, or redistribution of activities in the model are outlined. Second, it is demonstrated how the model reproduces the general pattern of past spatial development in the region. Third, results of simulations covering a wide range of potential overall economic and demographic development in the region are discussed.

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INTRODUCTION

Like other highly industrialized countries, the Federal Republic of Germany has experienced a fundamental change of direction in the development of its settlement structure. While the fifties and sixties were characterized by massive growth and expansion of urbanized areas at the expense of rural regions, the seventies saw an increasing outmigration of population and industry from the centers of the agglomerations to their less urbanized peripheries, resulting in a decline of population in all larger agglomerations and a decline of employment in some of them.

On the scale of one urban region, four phases of urban development encompassing this shift of direction can be distinguished (van den Berg and Klaassen 1978). Consider an urban region divided into two components: the urban core and the suburban periphery (see Figure 1). In phase 1, the urbanization phase, both components grow, but more growth occurs in the core. In phase 2, the growth curve of the urban core flattens, as more growth is attracted to the less urbanized periphery: this is the suburbanization phase. In phase 3, the urban core

*The research described in this paper was carried out at the Institute of Urban and Regional Planning, University of Dortmund, FRG.

declines, while growth continues in the suburbs at a diminishing rate; at some point in time the total region starts to decline. This phase may therefore be called the deurbanization phase. Phase 4 is the uncertain future.

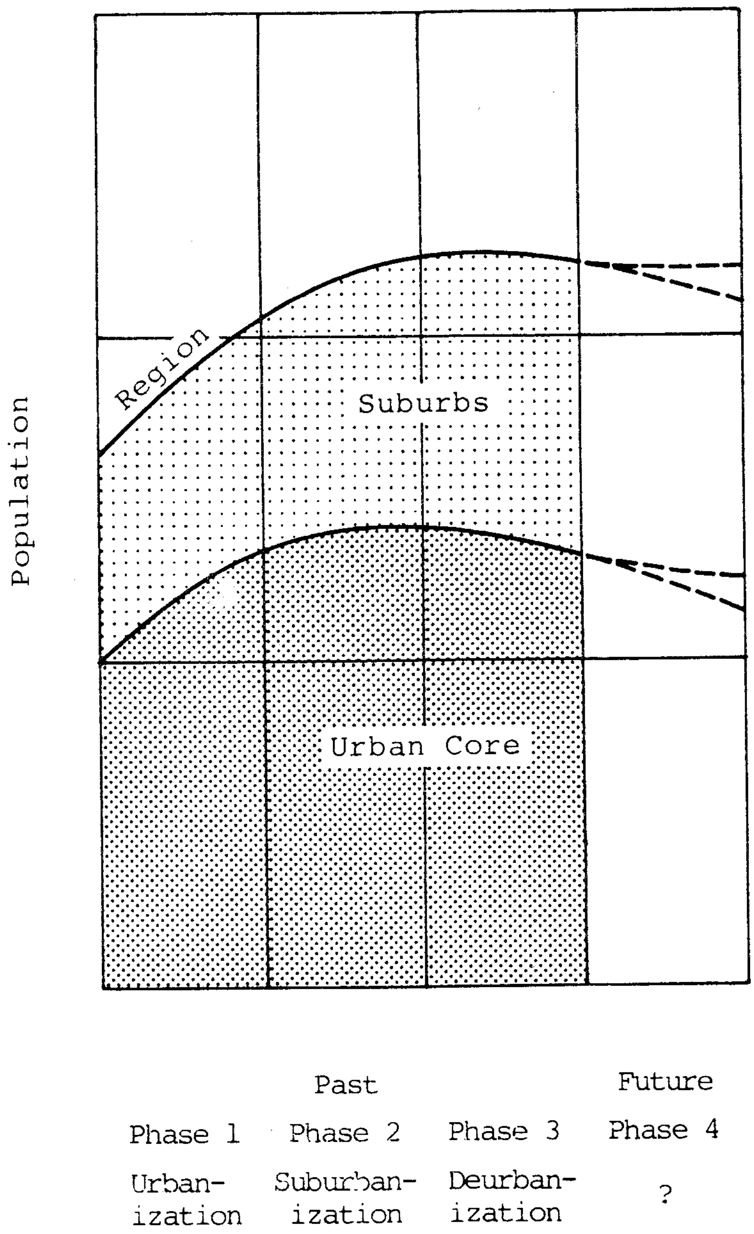


Figure 1. Urbanization, suburbanization, and deurbanization (van den Berg and Klaassen 1978).

The basic causes underlying phases 1 through 3 seem to be well known. At times of high overall population growth, job opportunities in cities used to be the major force behind the urbanization process. Rising incomes and modern transport technologies (the automobile) made suburbanization possible. Deurbanization does not seem to be a third, entirely new phenomenon, rather the continuation of suburbanization under conditions of overall population decline. However, there seems to be no agreement on the prospects of phase 4: Will deurbanization persist; will it level off; or will there be forces, such as rising costs of travel, which will stimulate a new contraction of urban form?

Unfortunately, regional science and related disciplines have had not much to offer to reduce the uncertainty about the future prospects of urban change. Empirical studies conducted in the seventies revealed a great variety of different patterns of spatial urban development under different economic and demographic conditions (e.g., Leven 1978; Hall and Hay 1980). Most authors agree that a great number of economic, demographic, social, and other factors contribute to urban change (Korcelli 1981), but how these factors do interact with the spatial urban system is still a question of much speculation.

Perhaps most successful, therefore, are studies that combine the results of intuitive reasoning in a scenario-like approach (e.g., Arras 1980). Quantitative models of urbanization have in the past been mostly growth oriented and contain no mechanism which enables them to produce forecasts of polarization reversal.

This is true for most demoeconomic models on a national or multiregional scale, which treat urbanization as a correlate of sectoral economic change that is not likely to reverse its path (see, for instance, Karlström 1980; Shishido 1982). But even elaborate models which forecast rural-to-urban migration as a function of urban-rural wage or employment differentials and include urbanization constraints such as land supply (e.g., Kelley and Williamson 1980), will not produce large migration flows going in the opposite direction. This can be expected from multiregional migration models (Rogers 1975; Rogers and

Philipov 1980) which therefore seem to be well suited to capture the population redistribution aspects of urban decline. However, as these models are based on the probabilistic interpretation of observed frequencies of past behavior, they will not forecast any kind of trend reversal unless explicitly told to. This makes them superior to any other model for short-term predictions, while in a long-term framework they are most suited for studying the demographic impacts of exogenously entered migration trends.

From the urban analyst's point of view, none of the national or multiregional models will capture the essential causes of urban decline, because they lack the spatial resolution necessary to take account of agglomeration diseconomies and scarcity of resources, most notably of land. Unfortunately, on the urban scale models of spatial development have also been designed only to allocate growth and therefore have failed to address the issue of urban decline altogether. This critique certainly applies to most Lowry derivative or interaction-based land use allocation models (Lowry 1964; Wilson 1974), although some of them do consider possible causes of urban decline such as aging of the population, growing unemployment (Gordon and Ledent 1980), or scarcity of buildable land (Putman 1980; Mackett 1980). However, these models fall short of reproducing the preference, economic, and other constraints determining urban location and relocation decisions. Models which attempt to do that, mostly in a microeconomic or random-utility framework, are either restricted to a limited sector of the urban process, (like the housing market, e.g., Kain et al. 1976; McFadden 1978), or are still too spatially aggregated to be of interest to the urban planner (e.g., Zahavi et al. 1981). And in none of them is urban decline actually modeled. To model growth *and* decline processes in the evolution of an urban system is the claim of a new generation of models based on bifurcation theory (Allen et al. 1981; Beaumont et al. 1981); however, their present results still seem to be at odds with the slow pace and virtual irreversibility of real-world urban change processes.

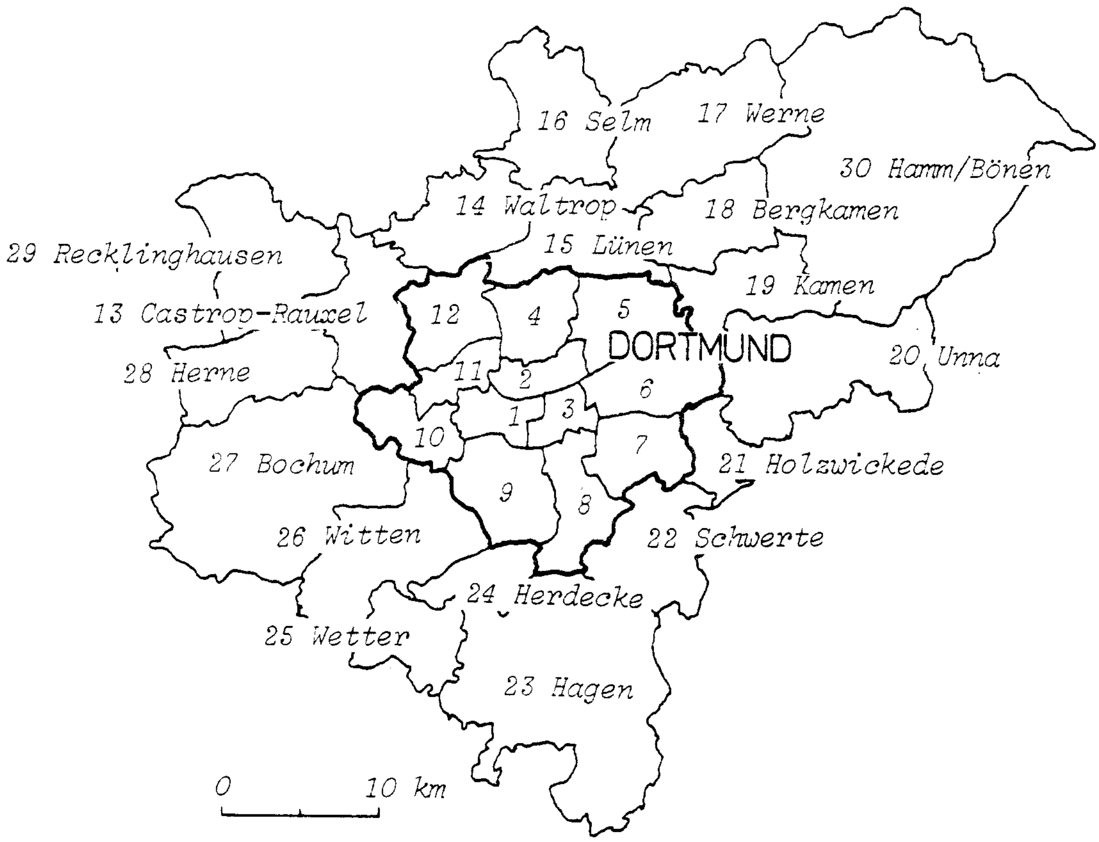
At the core of the difficulties in modeling spatial behavior lies the fact that there is still no agreed upon unified theory of spatial decision behavior of enterprises, households, or individuals. Such a theory would need to be so general as to explain spatial processes of growth and decline, agglomeration and deglomeration, and contraction and dispersal in agreement with empirically founded economic and social theories.

The model discussed in this paper is an attempt to contribute to such a theory. It was designed to simulate location decisions of industry, residential developers, and households; the resulting migration and commuting patterns; land use development; and the impacts of public programs and policies in the fields of industrial development, housing, and infrastructure.

The model is currently operational for the urban region of Dortmund, including Dortmund (pop. 610,000) and 19 neighboring communities with a total population of 2.4 million. For use in the model, the urban region is divided into 30 zones (see Figure 2, top). For summarizing model results, these 30 zones have been grouped into four subregions: (A) Dortmund core area, (B) suburban periphery, (C) Bochum area, and (D) Hamm (see Figure 2, bottom). In this paper, only subregions A (zones 1-12) and B (zones 13-22) will be considered, because they most clearly represent core and periphery. Results of all four subregions are discussed in Wegener (1981c).

It can be shown that the three-phase scheme of urbanization, suburbanization, and deurbanization of Figure 1 has been well replicated in the Dortmund region (see Figure 3).

The fifties clearly are the last years of the urbanization phase: the population of both the core and periphery grew with an annual rate of 2.2 percent and 2.0 percent, respectively. The sixties may be called the suburbanization phase: population figures of the core zones stagnate, while those of the peripheral zones continue to grow at an annual rate of about 0.5 percent. During the seventies deurbanization begins: The core declines at an average annual rate of 0.6 percent;



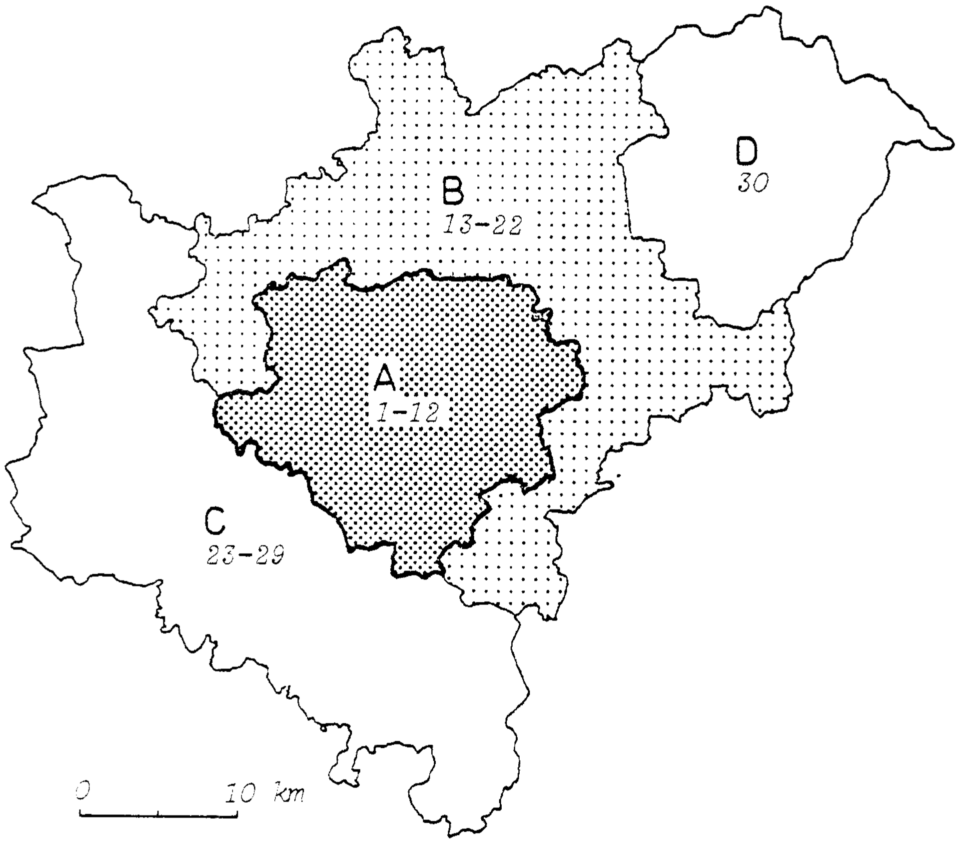


Figure 2. The 30 zones (top) and four subregions (bottom) of the Dortmund urban region.

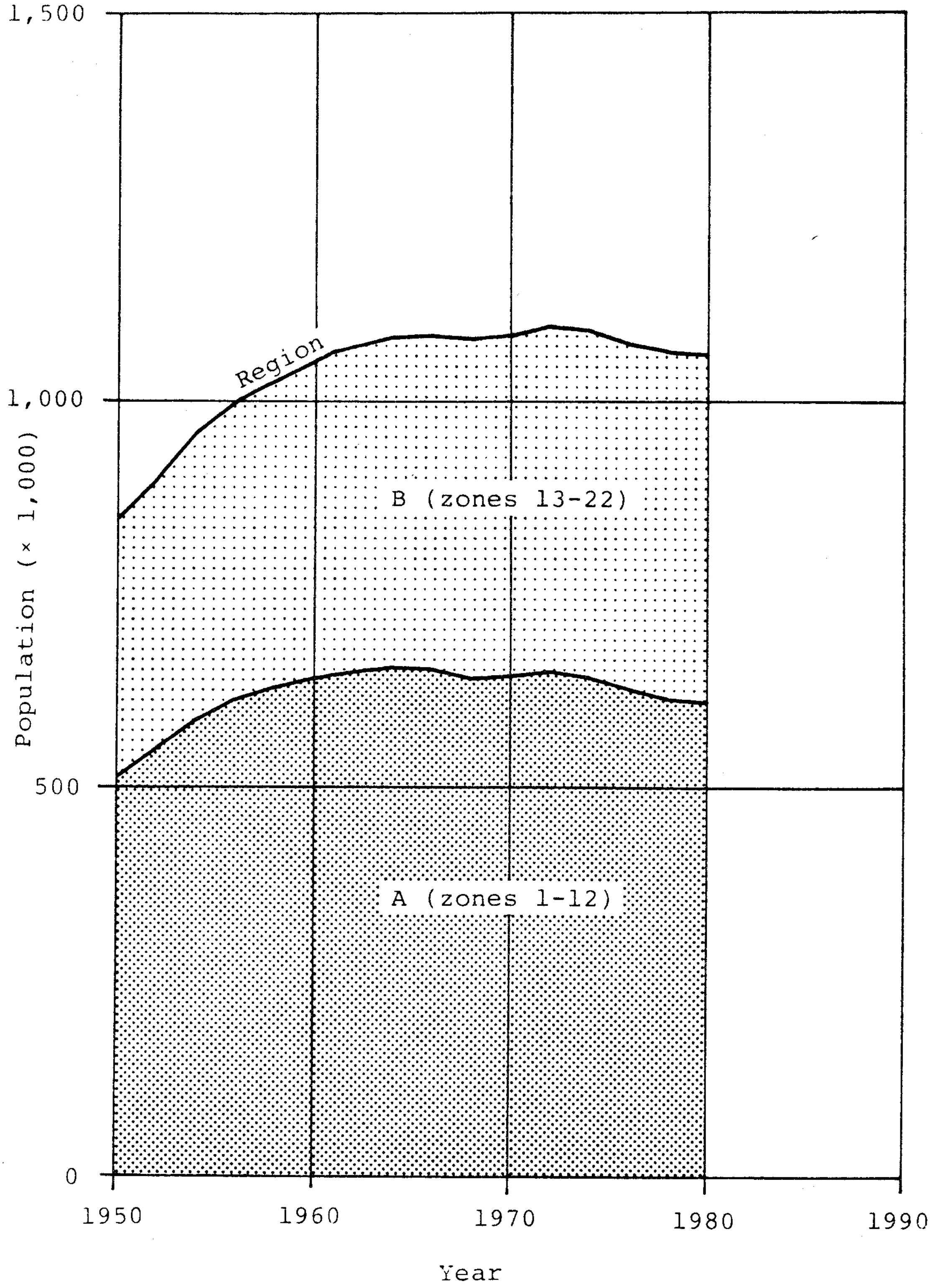


Figure 3. Urbanization, suburbanization, and deurbanization in the Dortmund region, 1950-1980.

growth continues in the peripheral zones, but with a diminishing rate of only 0.3 percent per year, resulting in a total annual loss of population of both the core and periphery of about 0.2 percent.

This paper addresses the question of what is going to happen in the region during the next decade, i.e., in phase 4. The discussion proceeds in three sections. In section 1, the mechanisms which control spatial growth, decline, or redistribution of activities in the model are outlined. In section 2, it is demonstrated how the model reproduces the general pattern of past spatial development in the region. In section 3, results of simulations covering a wide range of potential overall economic and demographic development in the region are presented.

1. MODELING URBAN DECLINE

Growth or decline of a region may have *exogenous* and *endogenous* causes. Exogenous factors are supply and demand on national and international markets, new technologies or products, trade and labor regulations, or the availability of public subsidies. These are the framework for regional development which can hardly be changed by decision makers in the region itself. However, regions can respond in different ways to changes in their external framework by adapting their economic and spatial structure more or less efficiently to changing external conditions. These responses are the endogenous factors establishing the comparative advantage of a region competing with other regions for capital, jobs, and people. The endogenous factors consist of *public* or *private* decisions. Public decisions are planning or implementation programs enacted by regional or subregional authorities in the fields of industrial development, public housing, land use, transport, or public facilities. Private decisions comprise location, relocation, and mobility decisions by private actors, such as firms, real estate investors, landlords, households, and individuals.

The endogenous adaptation of urban regions to changing exogenous conditions through public and private decisions is the subject of the model discussed in this paper. To model this adaptation, the model is organized in three spatial levels corresponding to the three lower tiers of the national planning system of the FRG:

(1) *Nordrhein-Westfalen*: a model of economic and demographic development in 34 labor market regions in the state of Nordrhein-Westfalen

(2) *Dortmund region*: a model of intraregional location and migration decisions in 30 zones of the urban region of Dortmund

(3) *Dortmund*: a model of land use development in one or more urban districts of Dortmund

The *first* model level is a multiregional demoeconomic model of the state of Nordrhein-Westfalen. Its regions are functionally defined as labor markets each one comprising one or more adjacent employment centers and their hinterland. On this level, information about exogenous, i.e., state-wide, economic development in terms of employment and productivity by industrial sector enters the model; the Nordrhein-Westfalen model predicts how under these exogenous preconditions regions compete to attract locating industries and migrants. Policy variables on this level in general represent policies of the state government in terms of public subsidies for industrial development, housing programs, or infrastructure investments in specific regions as well as also large-scale location or relocation decisions by major industrial corporations (see Schönebeck 1982).

The Nordrhein-Westfalen model yields forecasts of employment by industry and population by age, sex, and nationality in each of the 34 labor market regions as well as the migration flows between them. These results are the framework for the *second* spatial level of the model hierarchy. On this level, the study area is the urban region of Dortmund with its 30 zones (see Figure 2, top). For these 30 zones, the model predicts intraregional location decisions of industry, residential developers, and households; resulting migration and commuting patterns; land use development; and the impacts of public policies in the fields of regional industrial development, housing, or infrastructure investment programs.

The results of the Dortmund region model are employment by industry, population by age, sex, and nationality, households by size, income, age, and nationality, dwellings by size, quality, tenure, and building type, and land use by land use category for each of the 30 zones of the urban region, plus the migration and commuting flows between them. These results are in turn the framework for the *third* model level. On this level, the construction activity allocated to zones on the second model level is further allocated to any subset of 171 statistical tracts within the urban districts of Dortmund.

A comprehensive description of the three model levels and the information flows between them is contained in Wegener (1980). In the following sections of this paper, only those parts and causal links of the model which are of particular interest for modeling urban decline processes will be pointed out. The discussion will focus on the second, or urban region, level of the model, which is most relevant for modeling spatial patterns of urban growth and decline. The results of the first model level, i.e., regional totals of employment and population and of migration into and out of the region as generated by the Nordrhein-Westfalen model are taken as exogenous inputs. These inputs are then arbitrarily varied to provide a wide range of possible future courses of regional development.

1.1 The Urban System

The second-level, or urban region, model is a spatially disaggregate, recursive simulation model of spatial urban development. The model's spatial dimension is derived from the subdivision of the urban region into as many as 30 geographical subunits (zones) and its temporal dimension from two-year increments (periods) over a time span of up to 20 years.

Base year data of the model consist of zonal data on employment, population, households/housing, public facilities, and land use, and on network data representing two transportation networks for public and private transport, respectively.

Employment is classified in the model by 40 industrial sectors corresponding to the sectoral forecasts of the Nordrhein-Westfalen model. Several subsets of these 40 industries can be established, either by sector (e.g., service or nonservice) or by space or locational requirements, or zoning compatability.

Population is disaggregated in the model by 20 five-year age groups, by sex, and by nationality, i.e., native or foreign. In addition, population is represented as a distribution of households classified by nationality (native, foreign), age of head (16-29, 30-59, 60+ years), income (low, medium, high, very high), and size (1,2,3,4, 5+ persons). Similarly, housing is represented as a distribution of dwellings classified by type of building (single-family, multi-family, tenure (owner-occupied, rented, public), quality (very low, low, medium, high), size (1,2,3,4, 5+ rooms).

These 120 household and 120 housing types are further aggregated to 30 household and 30 housing types for use in the *occupancy matrix*. The occupancy matrix is a two-dimensional matrix each element of which represents the number of households of a certain type living in a dwelling of a certain type. Besides the occupancy matrix, there are households without dwelling and vacant dwellings (cf. Gnad and Vannahme 1981).

Public facilities are represented in the model by various facilities from the fields of health care, welfare, education, recreation, and transport. Land use is represented by 30 land use categories, ten of them being for built-up areas, i.e., different kinds of residential, commercial, or industrial land use.

Network data are link data of both networks containing link information such as length, travel time or speed, lines and headway (transit only), and capacity. Each zone is connected to both networks by at least one link.

1.2 Growth and Decline Processes

In this paper, urban growth or decline is discussed in terms of the spatial (zonal) distribution or redistribution of three major urban activities: *employment*, *housing*, and *population*. In this section, the variables representing these three activities will be traced as they are generated and changed during a model run.

1.2.1 Employment

The employment sector of the model is of great importance for modeling urban decline. It establishes the link by which major economic and technological developments such as economic recessions, sectoral change, or increases in productivity are entered into the simulation process.

The employment model treats each of the 40 industrial sectors as a separate submarket and makes no distinction between basic or nonbasic industries, i.e., all sectors are located or relocated endogenously. However, employment of all sectors may also be controlled exogenously by the model user in order to reflect the effects of major unitary events such as the location or closure of a large plant in a particular zone.

The model starts from existing employment $E_{si}(t)$ of sector s in zone i at time t. There are six different ways for $E_{si}(t)$ to change during a simulation period:

(a) Sectoral decline

Declining industries make workers redundant. It is assumed that this happens all over the region with the same rate. Then

$$E_{si}^{rs}(t,t+1) = E_{si}(t)\left[1 - \frac{E_s^*(t+1)}{E_s^*(t)}\right] \tag{1}$$

is the number of workers made redundant, where $E_s^*(t)$ indicates total employment of sector s in the region and $E_s^*(t+1)$ is the exogenous projection of total regional employment for time t+1. Declining industries are industrial sectors where $E_s^*(t+1) <$ $E_s^*(t)$, for all other sectors $E_{si}^{rs}(t,t+1)$ is set to zero.

(b) Lack of building space

One consequence of the ongoing mechanization and automation of most production processes is an increase of building floor space per workplace. Accordingly, in each period a number of jobs have to be relocated for no other reason than lack of space:

$$E_{si}^{rb}(t,t+1) = E_{si}(t)\left[1 - \frac{b_{si}(t)}{b_{si}(t+1)}\right] - E_{si}^{rs}(t,t+1) \tag{2}$$

where $b_{si}(t+1)$ is the projected floor space per workplace of sector s in zone i at time t+1, which will always be greater or equal to its previous value $b_{si}(t)$. How $b_{si}(t+1)$ is calculated is not discussed here because of lack of space. Of course, the redundant workers calculated in (1) can be subtracted from relocations, however, where redundancies exceed relocations, $E_{si}^{rb}(t,t+1)$ is set to zero.

(c) Large plants

If a major plant employing a large number of workers in a particular zone closes down, that is considered a "historical" even that no model can be expected to reproduce correctly. Therefore, the model user may enter such singular events exogenously into the model. Redundancies produced in that way are called $E^{rx}_{is}(t,t+1)$. Similarly, the user may exogenously specify where and when a major plant is to be opened. New jobs thus generated are indicated by $E^{nx}_{si}(t,t+1)$.

(d) New jobs in vacant buildings

Declining industries also leave vacant buildings which may be used by industries with similar space requirements. Before starting new buildings, it is therefore checked how many jobs of sector s can be accommodated in existing buildings. For this purpose, the 40 industrial sectors have been divided into groups with similar space requirements, e.g., heavy-load manufacturing or offices. The calculation of vacant building space is conceptually straightforward but somewhat technically complicated and will not be shown here. The total demand for new workplaces of sector s in the whole region is

$$E^{n*}_{s}(t,t+1) = E^{*}_{s}(t+1) - E^{*}_{s}(t) + \sum_{i} E^{rs}_{si}(t,t+1) + \sum_{i} E^{rb}_{si}(t,t+1) + \sum_{i} E^{rx}_{si}(t,t+1) - \sum_{i} E^{nx}_{si}(t,t+1) \qquad (3)$$

If this demand is less than the supply of suitable building space, it is allocated *pro rata* over the supply. The number of jobs accommodated in vacant buildings is indicated by $E^{nv}_{si}(t,t+1)$.

(e) New jobs in new buildings

For any remaining demand, new industrial or commercial buildings have to be provided. The remaining demand is

$$E^{n'*}_{s}(t,t+1) = E^{n*}_{s}(t,t+1) - \sum_{i} E^{nv}_{si}(t,t+1) \qquad (4)$$

This demand is allocated to vacant industrial or commercial land by the following allocation function:

$$E_{si}^{nc}(t,t+1) = \frac{C_{s\ell i} \exp\left(\alpha\ A_{s\ell i}(t)\right)}{\sum\limits_{i} \sum\limits_{\ell} C_{s\ell i} \exp\left(\alpha\ A_{s\ell i}(t)\right)}\ E_{s}^{n'*}(t,t+1) \qquad (5)$$

where $E_{si}^{nc}(t,t+1)$ are new workplaces of sector s built in zone i between t and t+1. $C_{s\ell i}$ is the *current* capacity for workplaces of sector s on land use category ℓ in zone i; as it is continually reduced during the simulation period, it bears no time label. $A_{s\ell i}$ is the *attractiveness* of land use category ℓ in zone i for sector s as of time t. The attractiveness of a location for a particular type of user is a weighted aggregate of relevant attributes of the location expressed on a standardized utility scale (see Wegener 1980). In this case, the attractiveness of a land use category in a particular zone for a building investor is composed of attributes indicating the neighborhood quality, the suitability of the site for the intended building use, and the land price in relation to expected profit. Where several building uses compete for a particular piece of land, the building use with the highest expected profit is assumed to win.

(f) Demolition

New buildings for industry, housing, or public facilities may be built on vacant zoned land or, under certain conditions, on land cleared by demolition of existing buildings. Demolition is handled by a special submodel which will not be discussed here for lack of space. To take account of relocation of jobs displaced by demolition, steps (d) and (e) are iterated several times during each simulation period.

1.2.2 Housing

The housing sector of the model is closely related to its population sector. The existing housing stock constitutes the supply side of the housing market and thus lastly determines the spatial distribution of population and all migration. Changes of the housing stock determine the future direction of spatial growth or contraction; new housing construction is affected on the *land and construction market*, where housing has to compete with other land uses. As before, there are several ways that changes of the housing stock may occur:

(a) Filtering

In each period, a portion of the housing stock is assumed to "filter" down the quality scale, i.e., to deteriorate by aging, which will eventually lead to decay and demolition, unless efforts to maintain and repair buildings are undertaken. These changes of the building stock are treated as events which occur to a dwelling with a certain probability in a unit of time. These probabilities, which are called *basic event probabilities*, are specified exogenously and aggregated to transition rates between quality groups of the aggregate (30-type) housing classification, using information about their internal composition from the disaggregate (120-type) classification. The result is a $K \times K$ matrix $\underset{\sim}{d}(t,t+1)$ of transition rates where K is the number of aggregate housing types. Multiplying the vector of dwellings with this matrix would yield the dwelling vector updated by one period.

The situation gets slightly more complicated by the fact that dwellings are associated with households by means of the *occupancy matrix* (see section 1.1). This requires a similar analysis of transitions to be made for households (see section 1.2.3). If $\underset{\sim}{h}'(t,t+1)$ is the transpose of an $M \times M$ matrix of transition rates of households and $\underset{\sim}{R}(t)$ is the occupancy matrix with dimensions $M \times K$ at time t,

$$\underset{\sim}{R}(t+1) = \underset{\sim}{h}'(t,t+1)\ \underset{\sim}{R}(t)\ \underset{\sim}{d}(t,t+1) \qquad (6)$$

is the occupancy matrix updated or aged by one simulation period.

Besides dwellings contained in the occupancy matrix, also vacant dwellings undergo the filtering process: vacant dwellings that may have been left over from the previous period or may have been created by the dissolution of households in the current period, or new dwellings that may have been built in the previous period and released to the market only now. All these are multiplied by the transition matrix $\underset{\sim}{d}$ and assembled into a vector $\underline{D}(t+1)$ of vacant dwellings.

(b) Public housing

Like in the employment model, the user may specify major changes of the housing stock in particular zones and years exogenously. This is a useful feature of the model for entering major public housing or rehabilitation projects.

(c) New housing construction

The submarkets of the housing construction model are the housing types of the aggregate (30-type) housing classification or rather a subset of them, as only good quality housing is assumed to be built.

The demand for new housing of type k to be built during the period is estimated by the model as a function of the price development in that submarket compared with other investment alternatives, i.e., as a function of its relative profitability. The price of housing of type k in zone i is reevaluated each period as a function partly of inflation and partly of the demand observed on the housing market of the previous period (see section 1.2.3):

$$r^h_{ki}(t+1) = r^h_{ki}(t)\left[1 + \Delta r^h_o(t,t+1)\right]\left\{1 + f\left[d^v_{ki}(t), u^o_{ki}(t)\right]\right\} \quad (7)$$

where $\Delta r^h_o(t,t+1)$ is the inflation rate of housing costs in the region between t and t+1 and $d^v_{ki}(t)$ and $u^o_{ki}(t)$ are the proportion of vacant dwellings and the average housing satisfaction of all households of type m occupying dwellings of type k in zone i, respectively, after the housing market simulation of the previous period, i.e., at time t:

$$d^v_{ki}(t+1) = \frac{\sum_i D_{ki}(t)}{\sum_i D_{ki}(t) + \sum_i \sum_m R_{mki}(t)} \tag{8}$$

$$u^o_{ki}(t) = \frac{\sum_i \sum_m u_{mki}(t) R_{mki}(t)}{\sum_i \sum_m R_{mki}(t)} \tag{9}$$

The housing demand thus estimated is allocated to vacant residential land by the following allocation function similar to (5):

$$D^n_{ki}(t,t+1) = \frac{C_{k\ell i} \exp\left[\alpha\ A_{k\ell i}(t)\right]}{\sum_i \sum_\ell C_{k\ell i} \exp\left[\alpha\ A_{k\ell i}(t)\right]}\ D^{n*}_k(t,t+1) \tag{10}$$

where $D^n_{ki}(t,t+1)$ are new dwellings of type k built in zone i between t and t+1, $C_{k\ell i}$ is the current capacity for dwellings of type k on land use category ℓ, and $A_{k\ell i}(t)$ is the attractiveness of land use category ℓ in zone i for housing type k. As before, the attractiveness measure is a weighted aggregate of attributes expressing neighborhood quality, the suitability of the site, and the land price in relation to expected profit.

1.2.3 Population

The population sector of the model is the place where long-term demographic and social developments such as changes of fertility or household formation patterns, of income distribution, and of life styles are introduced into the model.

The population model consists of two distinct but interrelated parts. The first part projects population in terms of persons classified by age, sex, and nationality. The second part projects population in terms of households classified by size, income, age of head, and nationality. The rationale for having these two parallel population models is that demographic *aging*, including births and deaths, is modeled best on the basis of individual persons, while for modeling *migration*, households seem to be the most appropriate decision subjects to be modeled. Of course, having two population models requires a reconciliation procedure where there are inconsistencies between their results.

Modeling aging and migration in two separate models may seem to be a step backward methodologically as compared with multiregional or multistate demographic models (Rogers 1975; Rogers and Philipov 1980). The primary reason for this approach is the desire to have a *causally* or *behaviorally* specified migration model incorporating concepts such as spatial choice, housing preference, budget and information constraints and, above all, the constraint of the current housing supply which may be the foremost determinant of intraregional or intraurban migration.

Linking a probabilistic aging model with a behavioral migration model poses problems of sequence, because what is modeled in two separate models in reality occurs in a continuous interwoven fabric of events. This simultaneity of aging and migration is, of course, reproduced much better in the integrated approach of multistate demography. Here, a much cruder approach is followed. First, all probabilistic (i.e., aging and household formation) processes are performed; then all migrations are processed one after another, just as if they occurred altogether on the last day of the simulation period. This sequence of model steps will be explained below.

(a) Aging

The aging submodel projects a population of individual persons classified by five-year age groups, sex, and nationality (native, foreign) by one simulation period, including births and deaths, on the basis of time-invariant life tables and dynamic, age-specific, and spatially disaggregate fertility projections, exclusive of migration. If $P_a^{sn}(t)$ is a population cohort of sex s and nationality n in age group a, for a simulation period of Δt years,

$$T_a^{sn}(t,t+1) = \frac{\Delta t}{5} P_a^{sn}(t) \qquad a = 1,\ldots,19 \tag{11}$$

are the number of transitions of sex s and nationality n from age group a to age group a+1 between t and t+1. Equation (11) assumes that within each five-year age group the respective five years of age are distributed equally. This is, of course, rarely ever the case. Better results are obtained by using

$$T_a^{sn}(t,t+1) = \frac{\Delta t}{5} \frac{P_a^{sn}(t) + P_{a+1}^{sn}(t)}{2} \tag{12}$$

whenever $P_{a-1}^{sn} < P_a^{sn} < P_{a+1}^{sn}$ or $P_{a-1}^{sn} > P_a^{sn} > P_{a+1}^{sn}$, i.e., whenever P_a^{sn} is neither a "peak" nor a "dip" in the age distribution (cf. Schönebeck 1982). Then, if q_a^s are age- and sex-specific survival rates,

$$P_a^{sn}(t+1) = \left[P_a^{sn}(t) + T_{a-1}^{sn}(t,t+1) - T_a^{sn}(t,t+1)\right] \left[q_a^s\right]^{\Delta t} \qquad a = 2,\ldots,19 \tag{13}$$

$$P_{20}^{sn}(t+1) = \left[P_{20}^{sn}(t) + T_{19}^{sn}(t,t+1)\right] \left[q_{20}^s\right]^{\Delta t} \tag{13a}$$

are the surviving population at time t+1. Births are calculated from the number of women of childbearing age at mid-period:

$$B_i^n(t,t+1) = \Delta t \sum_{a=3}^{10} \frac{b_{ai}^n(t) + b_{ai}^n(t+1)}{2} \frac{P_{ai}^{2n}(t) + P_{ai}^{2n}(t+1)}{2} \tag{14}$$

where $b_{ai}^n(t)$ are exogenously projected births per year per woman of nationality n and age group a in zone i, $P_{ai}^{2n}(t)$ at time t. Note that a zonal subscript has now to be introduced, because different fertility projections are used for each zone. Surviving babies are added to surviving infants of the first age group:

$$P_{1i}^{1n}(t+1) = \left(P_{1i}^{1n}(t) - T_{1i}^{1n}(t,t+1)\right)\left(q_1^1\right)^{\Delta t} + B_i^n(t,t+1)\ h\left(q_1^1\right)^{\frac{\Delta t}{\sqrt{2}}} \tag{15}$$

$$P_{1i}^{2n}(t+1) = \left(P_{1i}^{2n}(t) - T_{1i}^{2n}(t,t+1)\right)\left(q_1^2\right)^{\Delta t} + B_i^n(t,t+1)(1 - h)\left(q_1^2\right)^{\frac{\Delta t}{\sqrt{2}}} \tag{15a}$$

where h is a fraction indicating the probability that a newborn baby will be a boy. Dividing the exponent of the survival rate of newborn babies by $\sqrt{2}$ takes account of the fact that the number of newborn babies increases cumulatively over the period (cf. Wegener et al. 1982).

In addition to the above transitions in the age distribution, in each simulation period a proportion of the foreign population is transferred to the native population by naturalization (not shown).

(b) Household formation

There are basically two ways to forecast a household distribution for time t+1: either to use projected headship rates to calculate households of different types from age and sex information of projected population of time t+1, or to update household information of time t by modeling changes occurring to households over time. The latter approach has been followed here. The idea is, in essence, to calculate transitions between household states, in the same way as the population projection transitions between age groups are calculated.

Transitions between household states can occur on the following four dimensions:

nationality: naturalization

age of head: aging

income: rise of income, decrease of income, retirement, new job

size: marriage, divorce, birth, death, death of child, marriage of child, new household of child, relative joins household

The probabilities of occurrence of these transitions are again called *basic event probabilities*. Most of them can be determined endogenously from the population or employment submodels, but others have to be specified exogenously.

The basic event probabilities are then aggregated to transition rates of household types of the aggregate (30-type) household classification, using information about their internal composition from the disaggregate (120-type) classification. This is analogous to the conversion of event probabilities to transition rates in the housing submodel. The result is the $M \times M$ matrix $\underset{\sim}{h}(t,t+1)$ used already for updating the occupancy matrix $\underset{\sim}{R}$ in (6) in section 1.2.2., i.e., households and housing are updated in one common semi-Markov model.

There are special provisions necessary to provide for households outside of the matrix $\underset{\sim}{R}$, such as subtenant households, households currently without a dwelling, households being forced to move because of demolition of their dwelling, and new or "starter" households (for details, see Wegener 1980). These households are first aged by multiplication with $\underset{\sim}{h}$ and then assembled into a vector $\underline{H}(t+1)$ of households without dwellings. Similarly, a vector $\underline{D}(t+1)$ is assembled containing vacant dwellings (see section 1.2.2).

(c) Reconciliation of (a) and (b)

Consistency requires that the number of household members of a population equals the number of individuals in that population. Because of possible specification or aggregation errors, the results of the above two models projecting persons (a) and households (b) may not be consistent and need to be reconciliated. If that is the case, the results of model (a) are considered to be more reliable, and the household size groups are adjusted such that the number of household members matches the number of persons in the population without changing the number of households. This is achieved by shifting an equal proportion of households of each household size group up or down the household size distribution H_i^s, $i = 1,\ldots,5$, depending on the sign of the deviation ΔH of model (b) from model (a), thus preserving as much of the characteristic of the original distribution as possible:

$$(H_i^s)' = H_i^s + \frac{H_{i+1}^s - H_i^s}{\sum_{i=2}^{5} H_i^s\left(p_i^h - p_{i-1}^h\right)} \, |\Delta H| \quad , \quad \text{if } \Delta H > 0 \qquad (16)$$

$$(H_i^s)' = H_i^s + \frac{H_{i-1}^s - H_i^s}{\sum_{i=1}^{4} H_i^s\left(p_{i+1}^h - p_i^h\right)} \, |\Delta H| \quad , \quad \text{if } \Delta H < 0 \qquad (16a)$$

where p_i^h is the number of persons in a household of size group i.

(d) Migration of households

Intraregional or intraurban migrations are largely determined by housing considerations. Because of this, the migration submodel used here is in fact a *housing market* model.

The principal actors of the migration or housing market model are the landlords representing housing supply and the households representing housing demand. Landlords attempt to make a profit from earlier housing investments by offering their dwellings on the market; during a market simulation period they are assumed to keep volume of supply and prices fixed. Households looking for a dwelling try to improve their housing situation. They are assumed to act as satisficers while searching the housing market within given budgetary and informational constraints. The satisfaction of a household with its housing situation is assumed to be a utility function with the dimensions housing size and quality, neighborhood quality, location, and housing cost.

Modeling the housing market involves, among others, two methodological difficulties. The first one is the size of the problem. With only a modest disaggregation as in this model with its 30 household types, 30 housing types, and 30 zones, there are 27,000 different kinds of mover households each facing a theoretical choice set of 900 potential kinds of dwellings, or 24.3 million possible kinds of moves. For a variety of reasons, however, only a small fraction of these moves (two or three) are ever inspected before a choice is made, if there is any choice at all. The second difficulty lies in the fact that the housing market, unlike many others, is largely a second-hand market, because new dwellings constitute only a very small share of the housing supply in each market period. This means that on the housing market supply and demand are interlinked in an intricate way: With each move a vacant dwelling is occupied and thus removed from the supply, but at the same time a dwelling becomes vacant and is added to the supply. In effect, not the volume, but the composition of the supply has been changed.

To cope with these difficulties, a micro simulation approach using the Monte Carlo technique has been adopted to simulate the housing market as a sequence of search processes by households looking for a dwelling or by landlords looking for a tenant. This approach reduces the size problem by simulating only a sample of representative search processes, and it solves the problem of supply-demand linkage in an appealing and straightforward way by reinserting vacant dwellings into the housing supply immediately after each move.

The simulation of the housing market thus consists of a sequence of random selection operations by which hypothetical market transactions are generated. 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, therefore including starters, inmigrations, outmigrations, and moves within the region. The simulation of each market transaction has a sampling phase, a search phase, a choice phase, and an aggregation phase.

In the *sampling* phase, a household looking for a dwelling or a landlord looking for a tenant is sampled. This is done *pro rata* from households without a dwelling and from vacant dwellings, but households in the matrix $\underset{\sim}{R}$, i.e., who are occupying a dwelling, are sampled dependent on their propensity to move which is assumed to be related to their satisfaction, or rather dissatisfaction, with their present dwelling. The satisfaction of a household of type m with its dwelling of type k in zone i, u_{mki}, is a weighted aggregate of housing attributes with the dimensions housing size and quality, neighborhood quality, location, and housing cost, with $0 \le u_{mki} \le 100$. Then

$$p(k|mi) = \frac{R_{mki} \exp\left[\alpha(100 - u_{mki})\right]}{\sum\limits_{k} R_{mki} \exp\left[\alpha(100 - u_{mki})\right]} \tag{17}$$

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

In the *search* phase, the sampled household looks for a suitable dwelling, or the sampled landlord looks for a tenant for his dwelling. It is assumed that the household first decides upon a zone in which to look for a dwelling. If it lives and works already in the region, this is not independent from its present residence and work zone. The probability that the household tries zone i' is:

$$p(i'|mki) = \frac{\sum\limits_{k'} D_{k'i'} \exp(\beta\, s_{ii'})}{\sum\limits_{i'} \sum\limits_{k'} D_{k'i'} \exp(\beta\, s_{ii'})} \tag{18}$$

where

$$s_{ii'} = \rho \sum_j \frac{T_{ij}}{\sum_j T_{ij}} v(c_{i'j}) + (1 - \rho) v'(c_{ii'}) \qquad (19)$$

is an expression indicating the locational attractiveness of zone i' as a new residential location for a household now living in zone i and working in any of the zones j near i. The T_{ij} are work trips from i to j, $v(c_{i'j})$ and $v'(c_{ii'})$ are two different utility functions of generalized cost of travel between the new residential location i' and the workplaces in j and the old residential location i, respectively, and $0 \leq \rho \leq 1$ is a weight parameter. For a full discussion of $s_{ii'}$, see Wegener (1981b). The household then looks for a vacant dwelling in zone i'. The probability that it inspects a dwelling of type k' is

$$p(k' | mkii') = \frac{D_{k'i'} \exp(\gamma\, u_{mk'i'})}{\sum_{k'} D_{k'i'} \exp(\gamma\, u_{mk'i'})} \qquad (20)$$

In the case of the landlord, the search phase looks similar, but of course the sequence of steps is different. For a full description of all sampling and search probabilities, see Wegener (1981a).

In the *choice* phase, the household decides whether to accept the inspected dwelling or not. It is assumed that as a satisficer it accepts if it can improve its housing satisfaction by a considerable margin. Otherwise, it enters another search phase to find a dwelling, but with each attempt it accepts a lesser improvement. After a number of unsuccessful attempts it abandons the idea of a move.

If it accepts, all necessary changes in $\underset{\sim}{R}$, $\underset{\sim}{H}$, and $\underset{\sim}{D}$, multiplied by the sampling factor, are performed. This is the *aggregation* phase. Then the next market transaction is simulated. The market process comes to an end when there are no more households considering a move.

(e) Migration of persons

The migration flows generated by the migration or housing market model need to be translated into persons by age, sex, and nationality to allow for migration-induced changes of the population distributions of the zones. To this purpose, for each household type of the disaggregate (120-type) household classification, a vector p^g_{aikl}, $a = 1,\ldots,20$ is endogenously estimated containing the age distribution of its members such that $\sum_a p^g_{aikl} = p^h_i$, where p^h_i has the same meaning as in equation (16/16a). This estimation technique, which uses information such as the current age distribution of parents and past birth rate trajectories, would have to be discussed in another paper. As the number of households of each household type and the total of each population age group is known, the estimated values of $\underline{p}^g$ can be adjusted to conform with the age distribution of the total population by biproportional scaling techniques. By multiplying the number of households of each migration flow with the appropriate vector $\underline{p}^g$, all household migration flows can be expressed in terms of migrant persons by age, sex, and nationality. With this information, adjustment of the population distributions of the source and target zones to migration-induced changes is straightforward.

2. MODEL VS. REALITY

The model described in the preceding section has been calibrated using employment, housing, and population data of 1970 and 1972, work trip data of 1970, and migration data of 1970 and 1971. No particular effort has been made to statistically estimate all parameters. Where lack of uncompatibility of data, the form of the model functions, or the great number of variables and feedback relationships precluded statistical estimation, it was decided that model structure was more important than estimability. In such cases, "softer" approaches to determine parameter values including trial and error, expert opinion, and plausibility checks were applied. More details on the calibration techniques applied are contained in Wegener (1981b).

As a crucial test for the credibility of the model, it will now be demonstrated how well the model reproduces the general spatial development in the Dortmund region in the period 1970-1980 using *only* the information of the base year 1970 and one additional year therafter, 1972. For the sake of brevity, only predictions of population and migration flows will be inspected.

Table 1 shows measures of goodness-of-fit between observed and predicted figures for populations of the 30 zones of the Dortmund region. At first glance, the correspondence in terms of r^2 seems to be extremely high, but as is frequently the case with spatial data, this measure tends to be distorted by the predominance of a few very large observations. In such cases, a more meaningful measure of goodness-of-fit is the mean average percentage error (MAPE) calculated as

$$\text{MAPE} = \frac{\sum_i |X_i - X_i^o|}{\sum_i X_i^o} \cdot 100 \tag{21}$$

where X_i, $i = 1,\ldots,n$ are the predicted and X_i^o, $i = 1,\ldots,n$ are the observed values. A much more rigorous way to evaluate the goodness-of-fit is to neutralize the size effects by expressing the results in percent of their base values in the year 1970, i.e., looking only at the rates of change. Now the r^2 values give a more realistic picture of the performance of the model. It is interesting to note that in both kinds of analysis the MAPE statistic displays very similar values.

These results compare favorably with r^2 levels usually achieved with residential allocation models of the interaction type, in particular if one considers that mostly only the r^2 based on absolute numbers, as shown on the left-hand side of Table 1, are calculated (see, for instance, Floor and de Jong

Table 1. Goodness-of-fit of population predictions, Dortmund region, 1970-1980.

		Population			Population in % of 1970		
Year	n	r^2	t	MAPE[a]	r^2	t	MAPE[a]
1972	30	0.9997	288.3	1.3	0.7024	8.1	1.2
1974	30	0.9992	183.0	2.4	0.6540	7.3	2.2
1976	30	0.9986	140.0	3.0	0.6944	8.0	3.0
1978	30	0.9978	113.2	3.4	0.6838	7.8	3.9
1980	30	0.9965	89.2	4.1	0.6398	7.1	4.8

[a] mean average percentage error

Table 2. Goodness-of-fit of migration predictions, Dortmund region, 1970-1980.

	All migration flows				Migration flows < 1,000			
Period	n	r^2	t	MAPE[a]	n	r^2	t	MAPE[a]
1970-1971	961	0.9810	222.5	20.7	856	0.4853	28.4	71.2
1972-1973	961	0.9708	178.4	22.8	850	0.4927	28.7	71.2
1974-1975	961	0.9736	187.9	25.9	853	0.4198	24.8	78.9
1976-1977	961	0.9711	179.6	26.9	853	0.2684	17.6	89.5
1978-1979	961	0.9572	146.5	34.8	855	0.2622	17.4	86.1

[a] mean average percentage error

1981). Indeed, an inspection of prediction errors on a zone-by-zone basis showed that only 5 out of 30 zones had prediction errors of more than 10 percent over the ten-year period 1970-1980, and none over 15 percent, while 17 out of 30 zones were predicted with an error of less than 5 percent. It should be remembered that only the figures of the year 1972 were used for the calibration. However, it can also be observed that goodness-of-fit degrades, the more the simulation moves away from the calibration interval, which will be a concern of further research.

Table 2 shows the results of a similar analysis applied to migration flows. Again the r^2 values suggest a very good correspondence between observed and predicted flows, however, the MAPE statistic tells that the prediction errors still may be substantial (cf. Wegener 1981b). This is demonstrated by looking only at relatively small flows with an observed flow volume of less than 1000 migrants, and indeed, here the predictive performance of the model is much inferior and gets worse as the model proceeds in time. One reason for these errors in the small migration flows may be the insufficient resolution of the sampling procedure of the migration or housing market model, which could be improved at the expense of additional computer time. Needless to say that these errors in predicting migration are largely responsible for the errors of the population prediction discussed above. So improvements of the prediction of small migration flows are a key issue of further work.

More important for the topic of this paper is the question of whether the model correctly reproduces the process of spatial differentiation between the urban core and the suburban periphery. For this purpose again the two subregions A and B of the total urban region, which were used already in Figure 3 to portray the relation between core and periphery, are taken as units of reference. Figure 4 shows model results aggregated for these two subregions confronted with their respective counterparts in reality. The variable shown is again population in percent

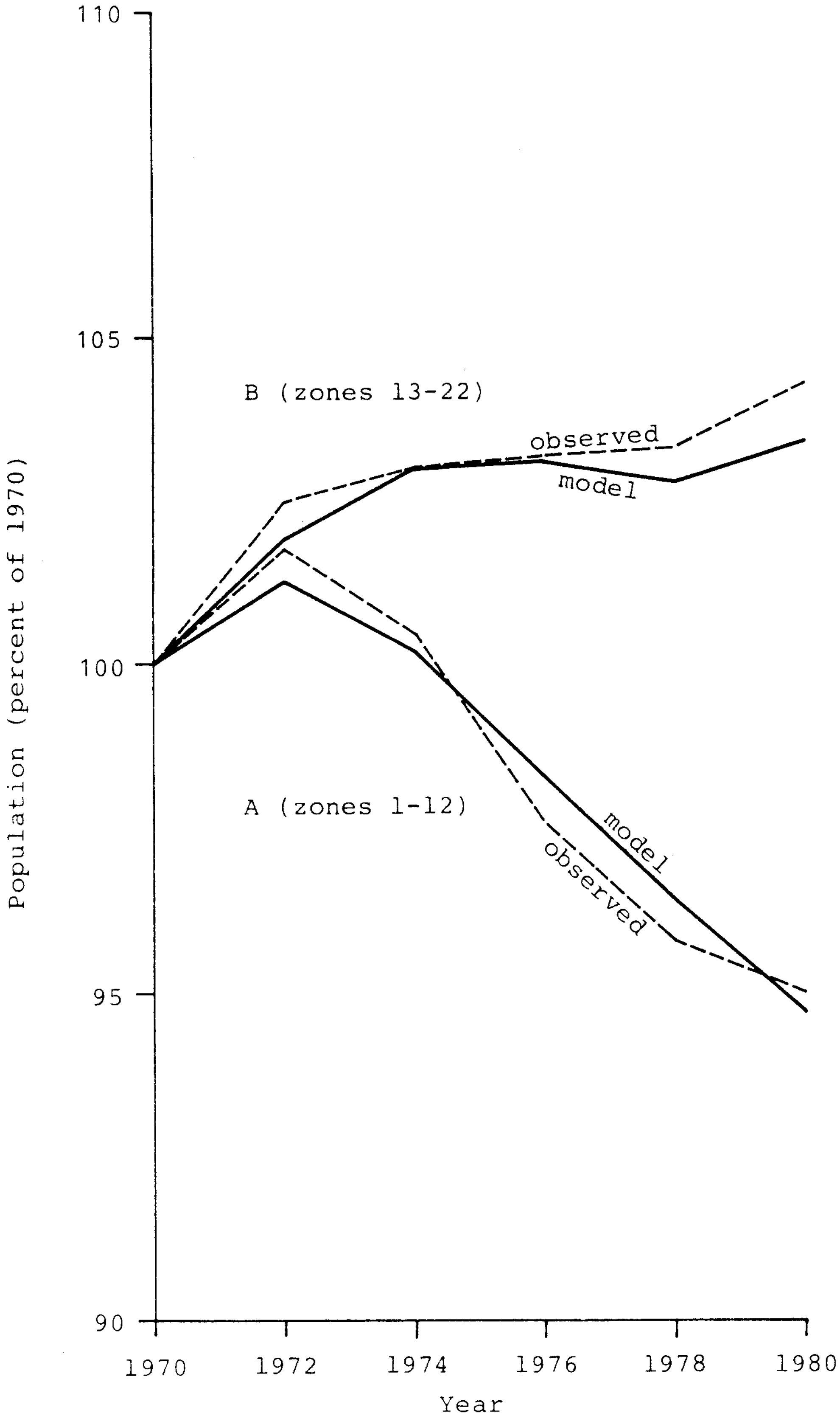


Figure 4. Population in subregions A and B of the Dortmund urban region, 1970-1980, in percent of 1970, observed and predicted.

of 1970 population, which is the most rigorous test conceivable. The result suggests that at this level of aggregation the model seems to closely follow reality, with no deviation ever exceeding one percent. As before, it should be noted that no zonal information after 1972 was used for calibration. Moreover, it is important to note that the two subregions A and B are only part of the whole model region (see Figure 2); i.e., they constitute a completely open system, which is to say that there are no hidden balancing mechanisms which keep the model from allocating more or less growth into C or D instead of A or B.

It is recognized that these few comparisons of model results with actual data are far too limited, far too aggregate, and too far from being perfect to establish any reasonable degree of credibility of the model at this stage. However, validation tests of other model variables such as housing and employment have been performed, and similar results have been achieved (see Wegener 1981c). In summary, the predictive performance of the model appears to be excellent on the aggregate level and still compares favorably with many other models on more disaggregate levels. Work on the calibration and validation of the model is continuing.

3. SIMULATION EXPERIMENTS

In the last section of the paper, the results of three simulation experiments will be presented as an illustrative example of application of the model.

Three scenarios have been defined for the simulation experiments. They differ only in the assumptions made for total regional employment and population after the year 1980:

SCENARIO 1 This scenario is the base-line simulation. It was derived from a base-line run of the top level, the Nordrhein-Westfalen model, which in turn was based on a synopsis of recent employment forecasts for Nordrhein-Westfalen (cf. Schönebeck 1982).

SCENARIO 2 The second scenario is a "growth" scenario. For this scenario, the base-line totals were arbitrarily modified by *increasing* regional employment by 7,500 jobs each year and by *reducing* outmigration by 15 percent and *increasing* inmigration by 10 percent.

SCENARIO 3 The third scenario is a "decline" scenario. For this scenario, the base-line totals were arbitrarily modified by *reducing* regional employment by 7,500 jobs each year and by *increasing* outmigration by 15 percent and *reducing* inmigration by 10 percent.

No particular meaning should be attached to the arbitrary specification of scenarios 2 and 3. It was simply intended to produce alternative scenarios with fairly massive changes of population and employment in order to find out how the model would react to extreme situations of growth and decline.

The principal results of the three simulations are displayed in Table 3 and Figure 5. All three scenarios are identical until the year 1980 when the first changes were introduced for scenarios 2 and 3.

The base-line simulation, scenario 1, clearly exhibits the continuation of present trends. Employment decreases only slightly by some 10,000 jobs in both subregions, although most recent unemployment figures suggest that this scenario may be far too optimistic (cf. Wegener 1981c). Both subregions decrease in population by about 55,000 persons or 5.2 percent over the decade, but the core (A) decreases faster with the effect that its share of the population of both subregions goes down from 57.4 to 55.4 percent (after having been 60.2 percent back in 1950). Despite this loss of population, housing construction goes on in both subregions because of rising incomes and changing

Table 3. Employment, housing, and population in subregions A and B of the Dortmund urban region, 1970-1980, simulation results.

Year	Scen-arios	A Absolute	A %	B Absolute	B %	A + B Absolute	A + B %
Employment							
1970		278,004	65.6	145,603	34.4	423,607	100.0
1980		268,620	64.1	150,460	35.9	419,080	100.0
	1	263,355	64.4	145,603	35.6	408,958	100.0
1990	2	281,693	63.9	158,905	36.1	440,598	100.0
	3	241,985	64.9	131,014	35.1	372,999	100.0
Housing							
1970		257,153	62.6	153,905	37.4	411,058	100.0
1980		282,183	60.7	182,802	39.3	464,958	100.0
	1	284,509	59.0	187,980	41.0	482,489	100.0
1990	2	292,113	59.7	202,155	40.9	494,268	100.0
	3	278,956	60.6	181,702	39.4	460,658	100.0
Population							
1950[a]		511,401	60.2	337,750	39.8	849,151	100.0
1961[a]		647,480	60.8	416,720	39.2	1,064,200	100.0
1970		640,865	59.6	434,633	40.4	1,075,498	100.0
1980		606,925	57.4	449,614	42.6	1,056,539	100.0
	1	554,701	55.4	446,432	44.6	1,001,133	100.0
1990	2	602,971	54.9	494,831	45.1	1,097,802	100.0
	3	520,019	56.6	398,664	43.4	918,683	100.0

[a]census data

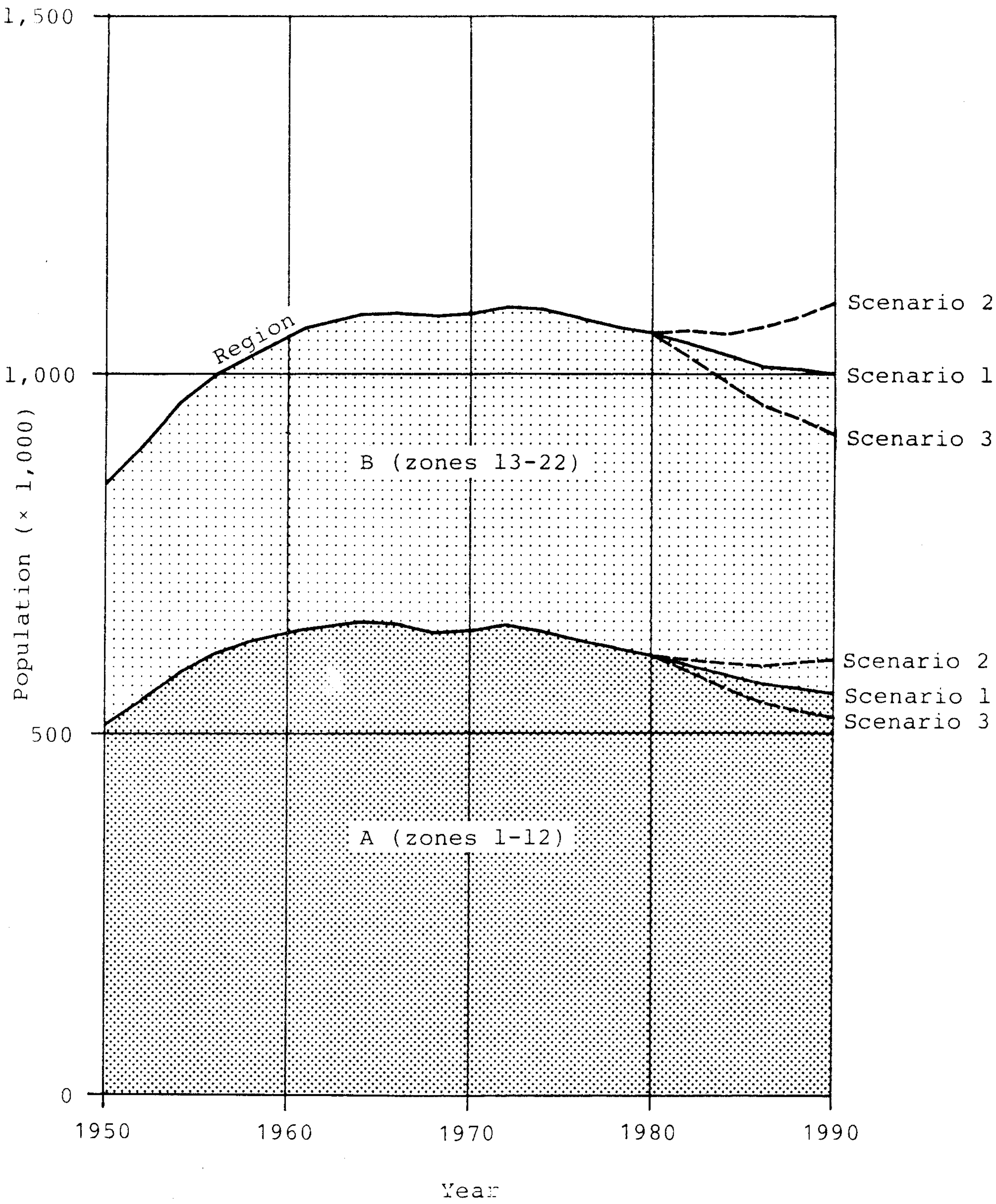


Figure 5. Population in subregions A and B of the Dortmund urban region, 1950-1970, actual development, and 1970-1980, simulation results.

household formation patterns. Of the 20,000 new dwellings built during the decade, however, only some 3,000 are built in subregion A, presumably because residential land in the core is less attractive yet more expensive than in the suburbs.

If scenario 1 is the most likely scenario of spatial urban development, scenarios 2 and 3 indicate the margin within which deviations from this most likely scenario may reasonably be expected to remain.

Scenario 2, the "growth" scenario, must today be considered as extremely optimistic with respect to the economic development of the region and certainly defines the upper limit of feasible development. More than 30,000 new jobs are created in subregions A and B during the decade, and nearly 100,000 additional migrants are attracted by them as compared with the base-line simulation. The suburban zones (B) attract more than their proportionate share of this additional inmigration bringing the percentage of population living in the core zones down to 55.0. This shift might have been even more pronounced, if the model had not run out of vacant residential land after 1985. This benefited the urban core, as now also less attractive, expensive land had to be utilized. Even with that, the model failed to provide enough dwellings for the new arrivals, so many of them had to move into formerly vacant, unattractive dwellings or become subtenants. This again benefited the core zones. Note that even under these abnormal circumstances, the core zones continue to decline in population. This may suggest that for a city like Dortmund there is presently no feasible way to prevent a further decline in population.

Scenario 3 is indeed a "decline" scenario, which given recent unemployment records, however, is not nearly as unlikely as originally supposed. Compared with the base-line simulation, jobs in the two subregions decline by some 36,000 or 8.8 percent, and more than 80,000 or 8.3 percent of the population migrate out of the region. This has the effect that practically no new dwellings are being built, in fact, the housing stock decreases by a constant rate of deterioration and eventually demolition. As most new dwellings, if they had been built, would have been built in the suburbs, this again benefits the core which in this scenario keeps a higher proportion of the population than in any other scenario.

CONCLUSION

In this paper, a modeling approach has been presented which attempts to interpret the process of urbanization, suburbanization, and deurbanization observed in contemporary urban agglomerations as a consequence of responses of various urban actors to externally induced changes of their economic and social environment. In brief, the model explains the macro behavior of the urban system through the micro behavior of its elementary components.

It has been shown that the model, at a certain level of aggregation, is capable of reproducing characteristic patterns of spatial choice behavior. In a simple illustrative application, the model has been used to investigate possible options of future spatial development in the Dortmund region. It could be demonstrated that there is no realistic scenario in which the urban core of the region would not continue to lose population during the next decade.

Future work on the model will focus on the validation and interpretation of the model results on a more disaggregate level. In addition, it is planned to extend the data base and time frame of the model back as far as to the year 1950 in order to reproduce a longer time period of urban evolution encompassing phases of urban growth as well as phases of suburbanization and eventually deurbanization.

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