Accessibility and its application to a dynamic model of spatial land-use distribution

by

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Transportation planning is based on the assumption that the distribution of land-uses determines the relations between them. With the help of appropriate models, it is possible to estimate the volumes which must be handled by the interconnecting transport links. The volumes, then determine the required quality of transportation infra-structure. On the other hand, experts have pointed out, that the development of transportation infra-structure does have an impact on the distribution of land-uses and also, for certain trip purposes, on the number of trips. This kind of feedback – inconvenient as it may be – can indeed render previous decisions obsolete. It may very well happen, that actual volumes of new urban roads serving the city centre will be much larger than originally calculated, since the improved level of service generates an intensified location of certain land-uses in the city centre. The response of the transportation planners and the politicians alike was mostly such, that they demanded further improvements in service quality for the links concerned without being aware of the fact that, owing to this action, the negative feedbacks would only be intensified. Instead of achieving a reduction in transportation, new and heavier volumes would be the result. This effect was observed in most of the cities of mid-west U.S.A. The consequence was a drain of the city centres, first of residential land-use, and later on also of workplaces, since the growing difficulties in transportation increasingly aggravated the exchange of people and commodities between the city centre and the periphery.

From the above, the question arises, whether one could not succeed in formulating a model which would make the growth and the distribution of land-uses in an urban region dependent on the quality of exchange-relations in the whole urban area and in individual sub-areas. Such a model could demonstrate and forecast this counterflow relationship which is not considered in gravitation models.

Although this basic hypothesis of my simulation model cannot yet be verified statistically, it is very probable as soon as the inner relations of an urban region, owing to the increasing sectoral and spatial differentiation of urban land-uses, become more significant than its external relations. In this case, the so-called 'urban multiplier', i. e. the development of the external relations, will no longer solely determine the growth of a city – although is still being presumend by some new models which aim at the same objective. The hypothesis is also substantiated by the observation, that a growing number of urban development planners deliberately or intuitively imply, that it is the spatial structure of a city which determines growth. Thus, for instance, the Hamburg economist Jürgensen once warned not to underestimate the significance of the internal urban land-use and spatial structure for the growth of a city. The interesting aspect is, that while urban development planning is based on future economic growth, this is now seen to depend largely on structural assets and not only on general national economic development which, according to previous practices of economists, has never been transformed into a spatial structure.

A model, which makes the development of urban land-uses dependent on interior urban exchange relations, must have two characteristics:

1. It must of necessity be dynamic, i. e. include a time dimension, since we are confronted with land-use changes.
2. The dynamic process must be inherent, i. e. the structure of the system itself determines its development and not some external factors.

The first, and in my opinion, the only scientists to explicitly introduce these two concepts of dynamic into their models are two Americans, J.W. Forrester (Industrial Dynamic and Urban Dynamic) and his assistant Meadow, who became noted for his so-called World Model ("Limitations of Growth").

I myself have adopted Forrester's dynamic simulation method for my model, but only with respect to format and not to its substance, since Forrester does not subdivide the urban system into sub-areas and essentially considers an other problem, i. e. the question of vertical mobility versus horizontal mobility which is my field of interest.

The general schematic of the feedback process shows that the internal structure of the land-use transportation system controls the changes of its elements. One distinguishes between level variables which together indicate the present state of the system, and flow values – the so-called rate variables – which show the absolute change of level variables per unit of time. Since it is of course not only the level variable illustrated here which determines its own change, but several other or all level variables are involved, the feedback-arrow was drawn as a dotted line.

To construct the model we must first define and then combine all level and rate variables. In doing so, we distinguish between workplaces and residential land-use which, however, as far as the model structure is concerned, differ only in detail from each other.

The level variables always indicate the quantity of a certain land-use, both in the urban region as a whole, and in a given sub-area i

For residential land-use, the rate variables are as follows:

1. New residential population moves into the urban

region (NWG).

2. New residential population moves into sub-area i (NWT_i).

This rate variable is composed of

a) persons coming from areas outside the urban region,

b) persons having migrated or having been displaced from other sub-areas.

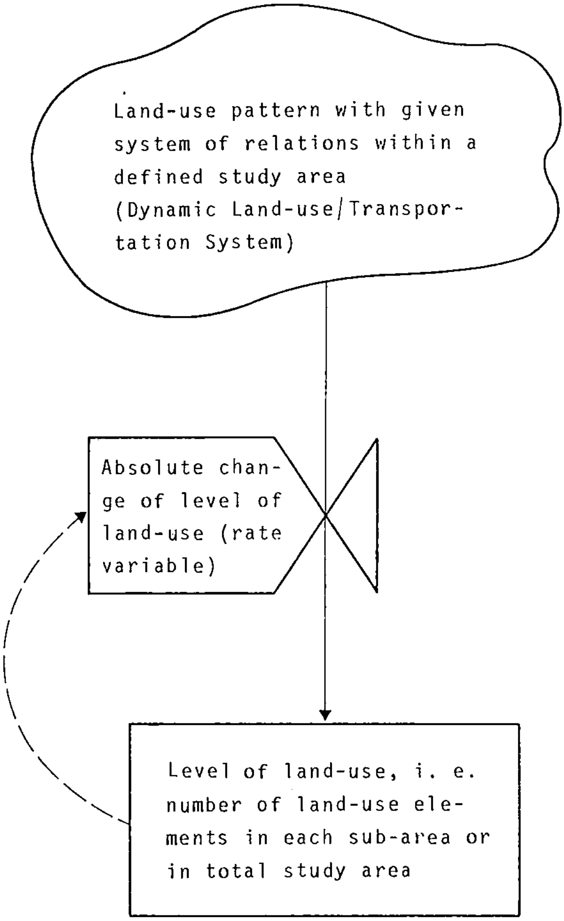


Fig. 1 – Schematic of feed-back process

3. Residential population migrates from sub-area i ('voluntary' migration AWT_i) 'Voluntary', however, does not imply that there are no social pressures.

4. Residential population is displaced from sub-area i ('forced' migration VWT_i). 'Forced' migration means, that one land-use is displaced from a sub-area by another land-use which is socially more powerful and curtails its former share of land.

5. Natural growth of residential population in sub-area i (NET_i).

6. Residential population leaves the urban region (AWG).

The rate variables for workplaces are of the same tenor, with the only exception that now there is no 'natural growth'. This is not quite correct, since the location of workplaces depends on whether an enterprise is already in the sub-area concerned or not, i. e. whether it is a newcomer or wishes to expand. Neither the theoretical nor the empirical data, however, allow to differentiate between these two categories.

Next, the feedbacks, i. e. the values of the rate variables must be determined hypothetically. This is done by means of so-called determining factors which must be composed of the level or other rate variables respectively. To illustrate the two most important determining factors, let us look at the rate variable 'new residential land-use moves into sub-area i'.

We consider two land-uses (residential and work) and the relationships between them (commuters). Moreover, it is assumed that the land-uses are distributed over three sub-areas, and that the workingplaces are socially stronger and thus able to displace residential land-use. The feedbacks are then as follows:

1. All level variables have a two-fold influence on the determining factor 'accessibility' (E_i):

(i) in a direct manner, via the relation between the two land-uses,

(ii) indirectly via the loads on the transport infrastructure which, in turn, influence spatial interaction (deterrence function, w_{ij}^{-1}). Thus, accessibility is a measure of the present quality of the spatial ralations of a particular sub-area with respect to the exchange-process between land-uses. It may adopt values ranging from 0 to 1, 1 indicating optimal conditions of exchange. Since we have only one relation, value E_1 (B) for the relation is equivalent to value E_1 (F) for the land-use.

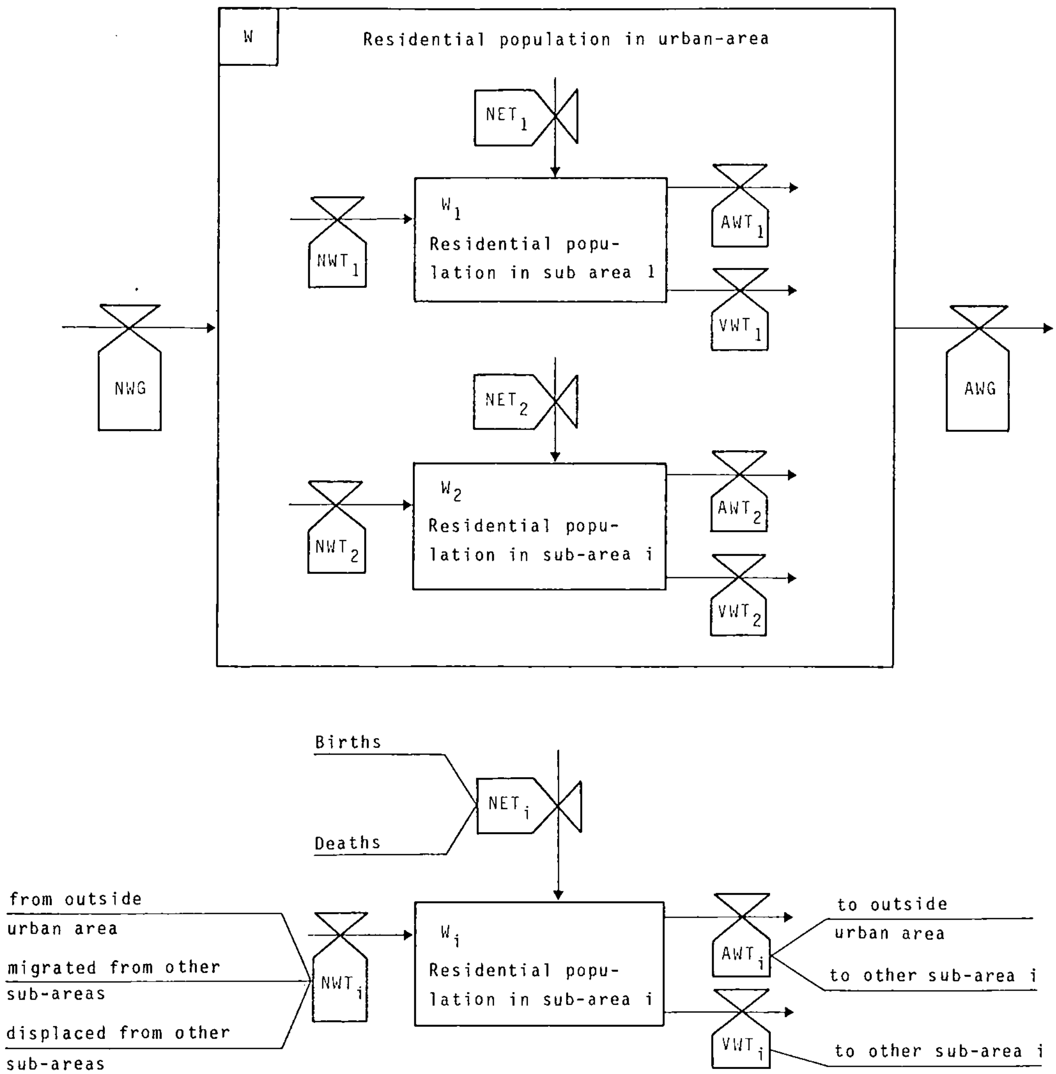
2. The quantity of residential population in sub-area 1 $(W)_1$, minus the number of residents prepared to migrate from sub-area 1 (AWT_1), yields the present total area demand for housing in subarea 1 (GN_1). Total demand, GN_1, in turn, represents the area factor (RF(F)) which signifies the additional growth potential due to available residential land reserves. This factor, too, may range between 0 and 1, 1 indicating optimum growth potential.

The area factor (RF(F)) is furthermore influenced by the proportion of land assigned to residential use in sub-area 1 (RA_1(F)) which is constantly threatened by possible displacement through workplaces. Furthermore it also depends on the value assigned to available residential land in the eye of demand, i. e. on what is known as 'potential' which indicates the quantity of attractions (in this case represented by workplaces). No matter how large the area, if there are no attractions, the area factor will still be 0.

3. The determining factors accessibility, area factor, and the absolute quantity of residential land-use in sub-area 1, now control the value of the rate variable 'new residential population moves into sub-area 1', using the absolute number of residential population as weight or agglomeration factor. Presenting only this one rate variable demonstrated the variety and complexity of feedback processes. In the following our task will be to determine, for each individual rate variable, the dependence on its determining factors. Thus, we shall arrive at the basic hypotheses of the simulation model.

1. DETERMINING FACTORS AND BASIC HYPOTHESIS FOR THE RATE VARIABLE 'NEW WORKPLACES MOVE INTO THE URBAN AREA' (NAG)

The rate variable 'new workplaces move into the urban area' is controlled by the weighted total accessibility. This is the sum of the accessibilities of all individual sub-areas and describes the quality of interrelationships within the urban system. Weighting will include both the relative quantity of land-uses in each sub-area and its area factor, i.e. the indicator for land which is still at disposal. It may



Legend of rate variables:

NWG = new residential population moves into urban-area

NWT_i = new residential population moves into urban-area i

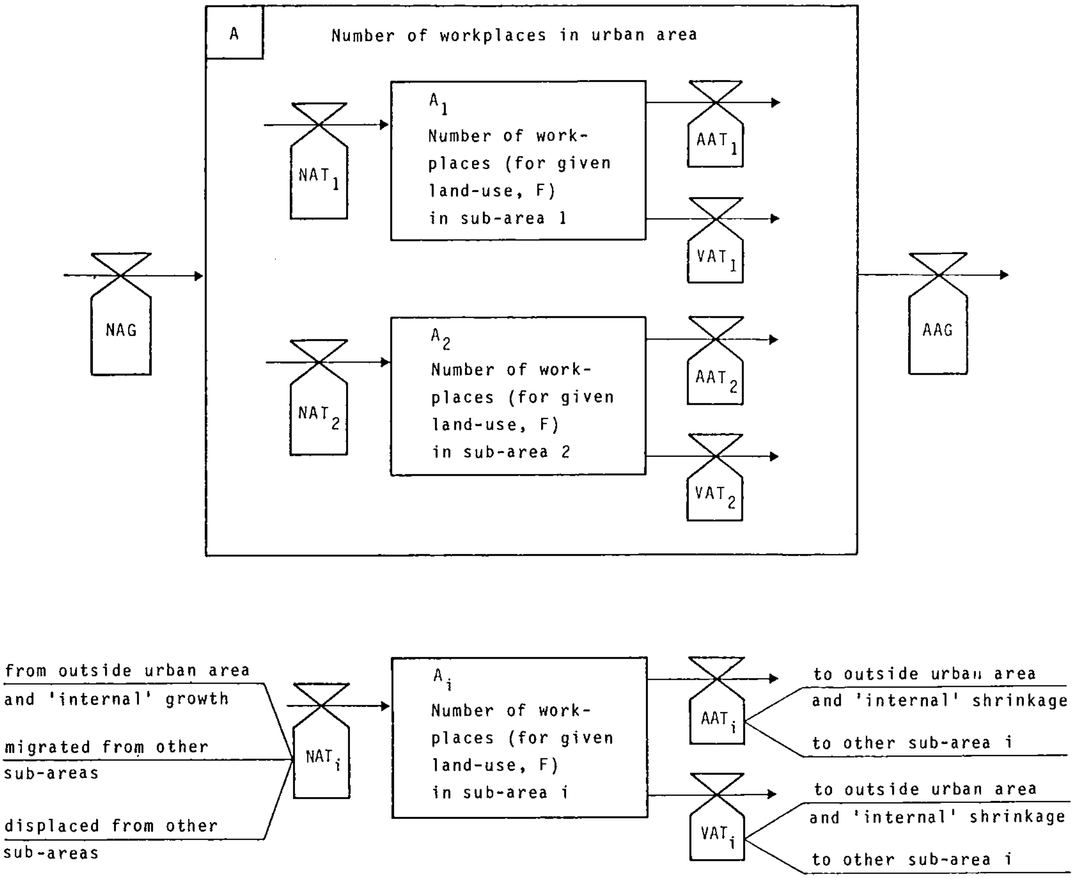
AWT_i = residential population migrates from sub-are i (voluntary migration)

VWT_i = residential population is desplaced from sub-area i (forced migration)

NET_i = natural growth of residential population in sub-area i (difference between births and deaths which, unlike all values of other change variables, may also be negative)

AWG = residential population leaves urban-area

Fig. 2 – Model structure (for residential population) and combination of rate variables for a given sub-area.



Legend of rate variables:

NAG	=	new workplaces move into urban area
NAT_i	=	new workplaces move into sub-area i
AAT_i	=	workplaces migrate from sub-area i (voluntary migration)
VAT_i	=	workplaces are displaced from sub-area i (forced migration)
AAG	=	workplaces leave urban area

Fig. 3 – Model structure (for workplaces) and combination of rate varables for a given sub-area

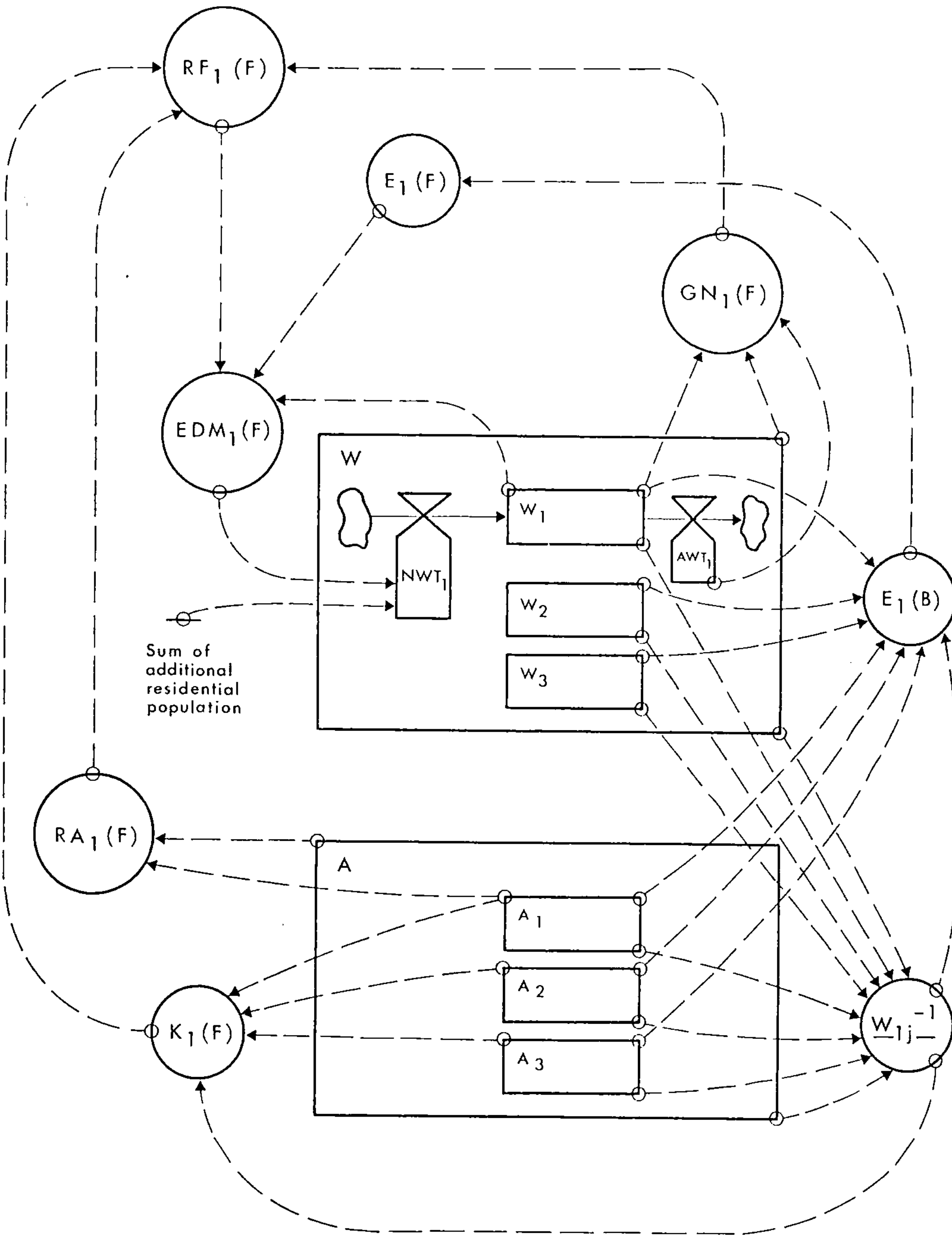


Fig. 4 – The complex influence of all level variables of the system on the rate variable NWT_1 (new residential population moves into sub-area 1)

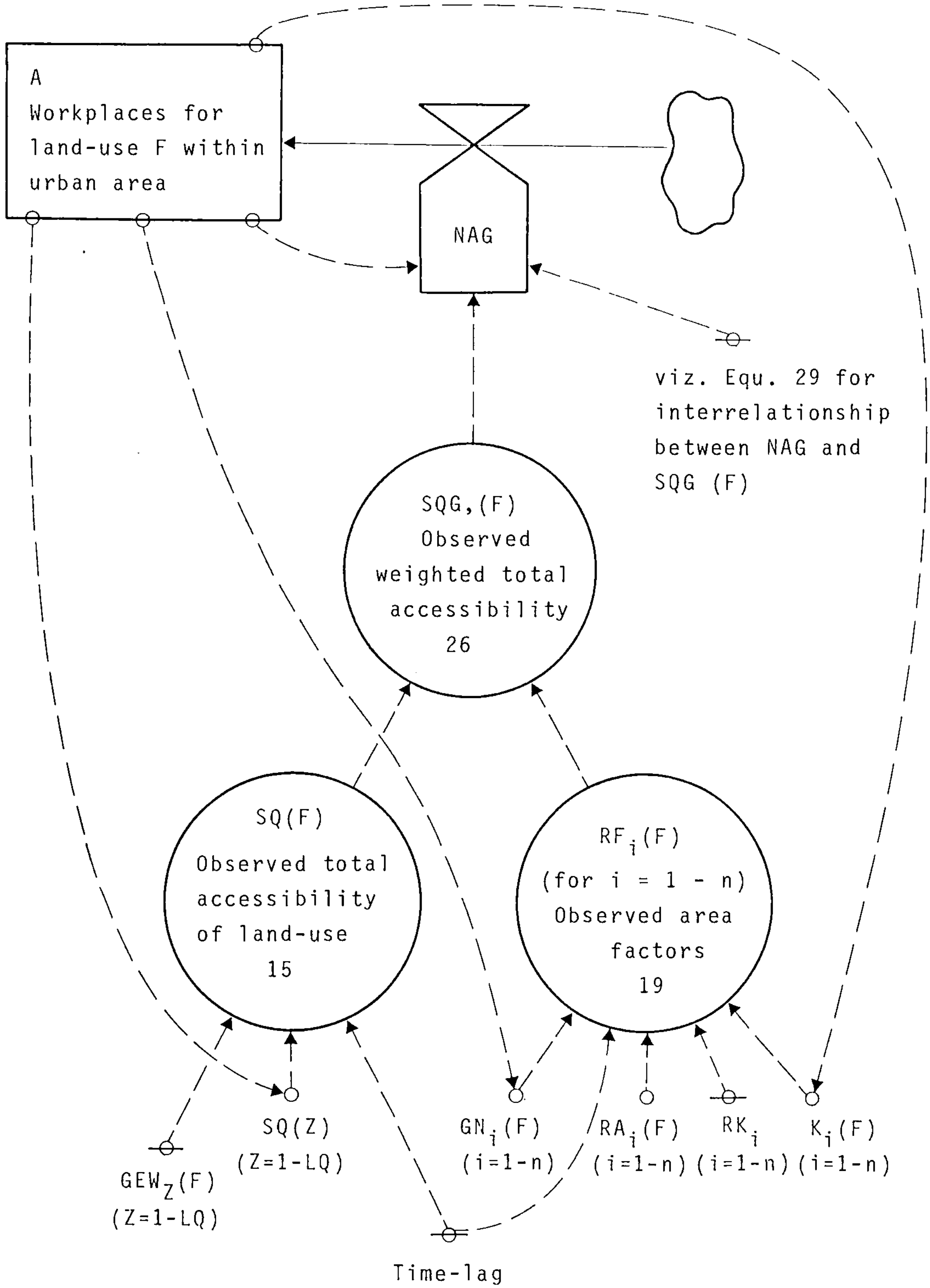


Fig. 5 – Relationship between rate variable NAG and its determining factors

happen, for example, that a land-use which is primarily concentrated in the city centre and has a comparatively high accessibility, is assigned a lower weighted total accessibility, if land reserves in the city centre are small. We shall see, that this is a very important fact to be considered in the model.

The first basic hypothesis now reads as follows:

The higher the total accessibility of workplaces in an area (it may also adopt values ranging between 0 and 1), weighted by area factors, the higher will be the percentage of gross growth within that area.

In combination with the present absolute quantities of land-uses in the urban area (level variable) the rate variable 'new workplaces move into the urban area', can be determined for each period of time.

This hypothesis does not apply to the corresponding rate variable for residential land-use. Since in a closed system the number of employees must always be equivalent to the number of workplaces, the quantity of new residential land-use will only be calculated at the end of overall balancing.

Since the following hypotheses apply to both residential land-uses and workplaces, there will no longer be any differentiation between them.

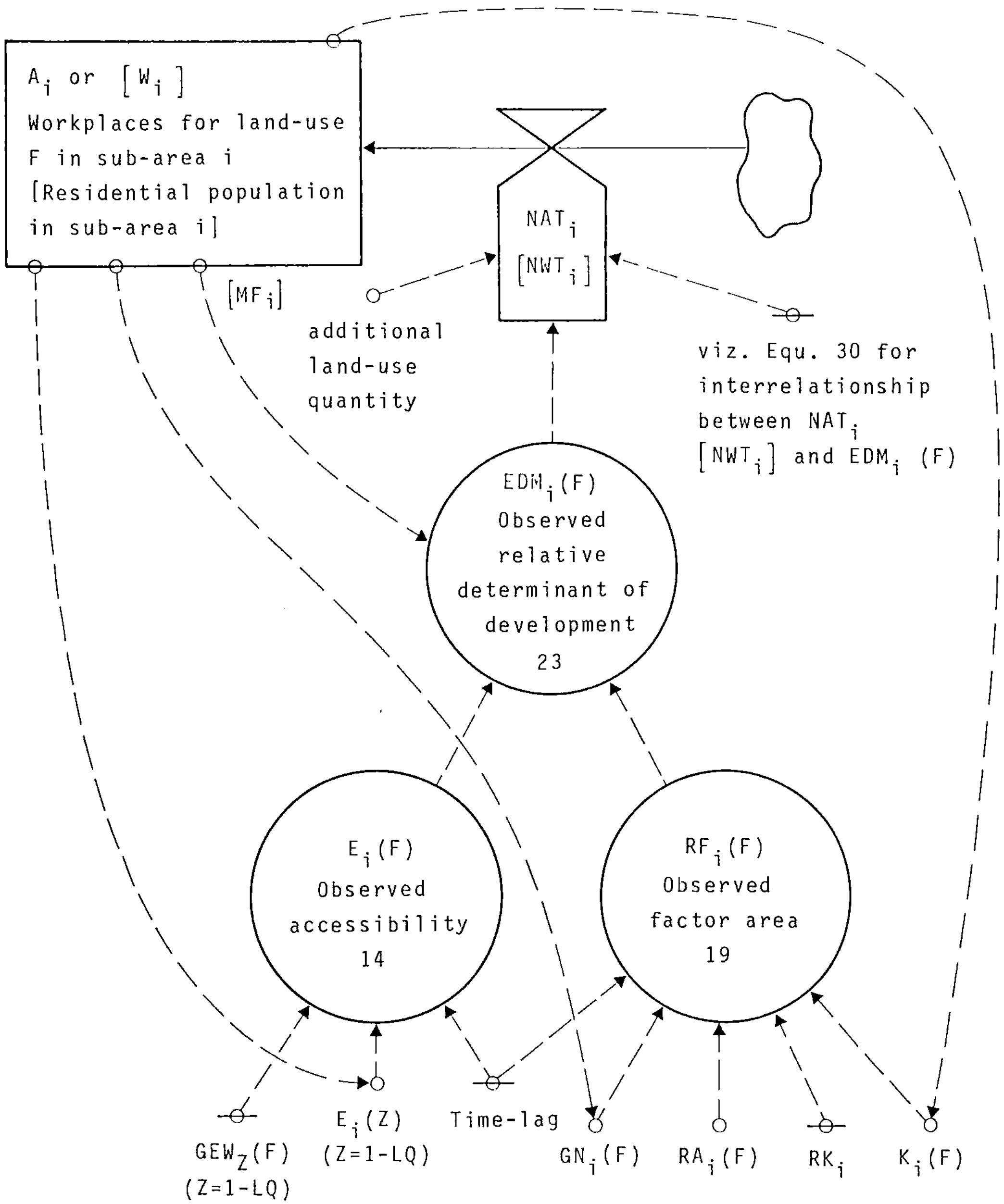


Fig. 6 - Relationship between rate variables NAT_i and $[NWT_i]$, resp. and their determining factors

2. DETERMINING FACTORS AND BASIC HYPOTHESIS FOR THE RATE VARIABLE 'NEW LAND-USES MOVE INTO A PARTICULAR SUB-AREA i' (NAT_i AND NWT_i, RESPECTIVELY)

We have already discussed the determining factors. Accessibility, area factor, and present absolute quantity of land-uses are combined, by multiplication, to so-called development determinants. Then the hypothesis reads:

The higher the relative development determinant of a sub-area, the higher will be the proportion of the quantity of land-uses to be established in the urban system.

3. DETERMINING FACTORS AND BASIC HYPOTHESIS FOR THE RATE VARIABLE 'LAND-USES MIGRATE FROM SUB-AREA i' (VOLUNTARY MIGRATION, AAT_i AND AWT_i, RESPECTIVELY)

'Voluntary' migration depends solely on the accessibility of a sub-area. The hypothesis reads:

The higher the accessibility of sub-area i for a given land-use, the lower the proportion of 'voluntary' migration from the sub-area considered.

The rate variable can be calculated for each period of time together with the present absolute quantity of land-use in each sub-area.

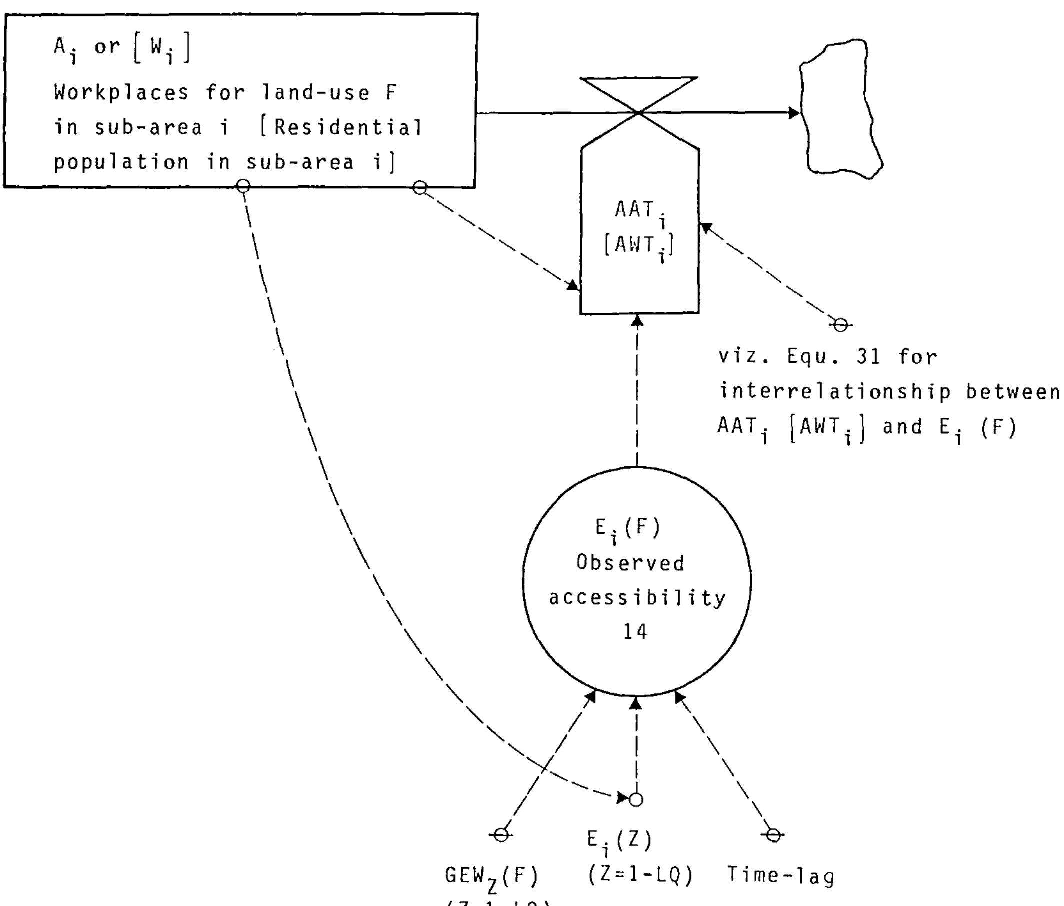


Fig. 7 – Relationship between rate variables AAT_i and $[AWT_i]$, resp., and their determining factors

4. DETERMINING FACTORS AND BASIC HYPOTHESIS FOR THE RATE VARIABLE 'DISPLACEMENT OF SOCIALLY WEAKER LAND-USES' ('FORCED' MIGRATION, VAT_i, VWT_i).

The quantity of a displaced land-use depends on its own degree of land-occupancy and on the degree of land-occupancy of other uses which are socially stronger. The degree of land-occupancy for each land-use and sub-area is defined as the ratio between total land demand and the corresponding land supply. The hypothesis reads:

The higher the degree of land-occupancy of a socially stronger land-use, the higher will be the quantity of displaced land-uses, of a socially weaker nature, provided that these have exhausted their share of land and total land within the sub-area cannot be extended.

The arguments for this hypothesis lie in the fact, that a high degree of occupancy limits further growth. Powerful land-uses will therefore attempt, at the expense of other land-uses, to increase their share of land in attractive sub-areas. In our economic and social system this is done via the price of land.

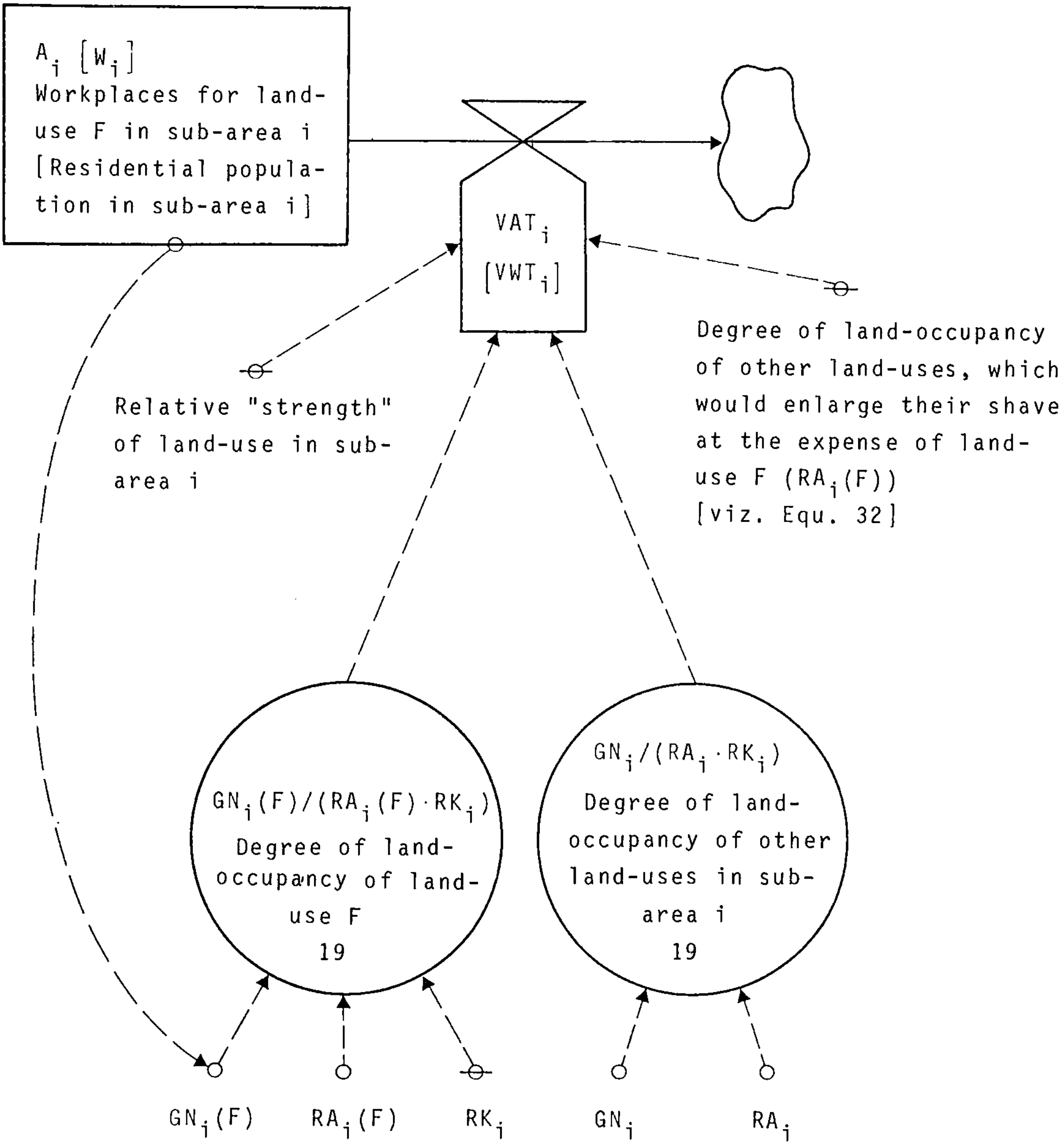


Fig. 8 – Relationship between rate variables VAT_i and $[VWT_i]$, resp., and their determining factors

5. DETERMINING FACTORS AND BASIC HYPOTHESIS FOR THE RATE VARIABLE 'LAND-USES LEAVE THE URBAN AREA' (AAG, AWG, RESPECTIVELY).

The rate variable 'land-uses leave the urban area' is determined by the total accessibility of the system. However, there is no weighting by use of area factors as was the case when dealing with new land-uses. Thus, it is assumed that, as for 'voluntary' migration from sub-area i, the area still at disposal has no influence on the rate variable 'land-uses leave the urban area'. The hypothesis reads:

The higher the total accessibility of a land-use within the urban system, the lower the proportion of migrants sumultaneously leaving the urban area out of each sub-area.

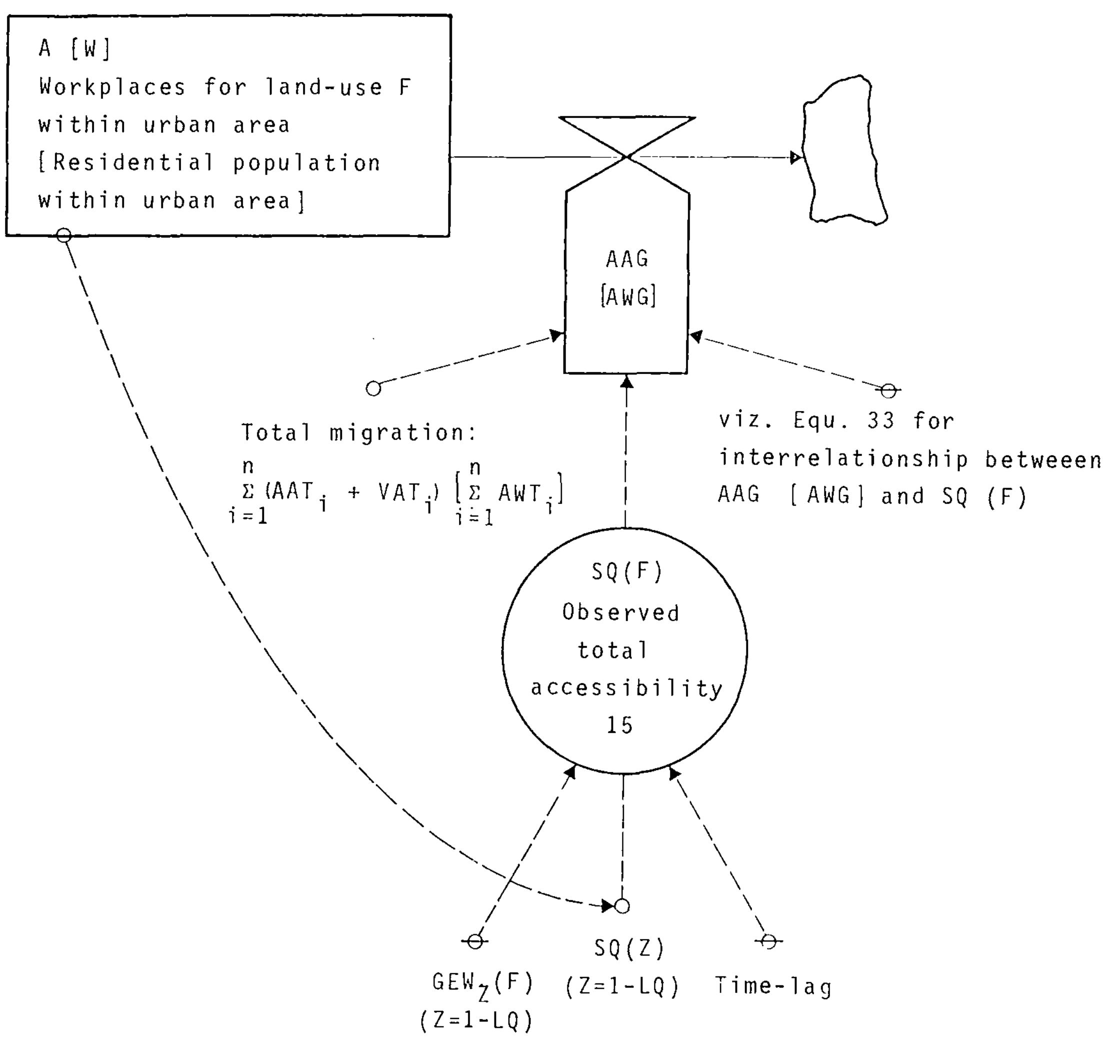


Fig. 9 – Relationship between rate variables AAG and [AWG], resp., and their determining factors

6. THE RATE VARIABLE 'NATURAL DEVELOPMENT OF THE RESIDENTIAL LAND-USE' (NET_i) IS AS YET NOT INCLUDED IN THE FEEDBACK-PROCESS AND IS DETERMINED INDEPENDENTLY BY MEANS OF REGRESSION ANALYSIS.

Two other important variables have also not yet been considered in the feedback-process:

Area demand of transportation infrastructure and commuter mobility. There are, however, no difficulties to integrate them at a later stage.

For the simulation model the hypotheses are now transformed into mathematical functions. These functions must be calibrated, and for this, additional investigations are necessary. I should emphasize, however, that it is more important to combine the hypothetical interrelationships into a model of the complex social urban system than to endulge into extensive empirical analysis. This is the only way to analyse feedback phenomena, even if they do not exaxtly correspond to reality as far as their quantities are concerned.

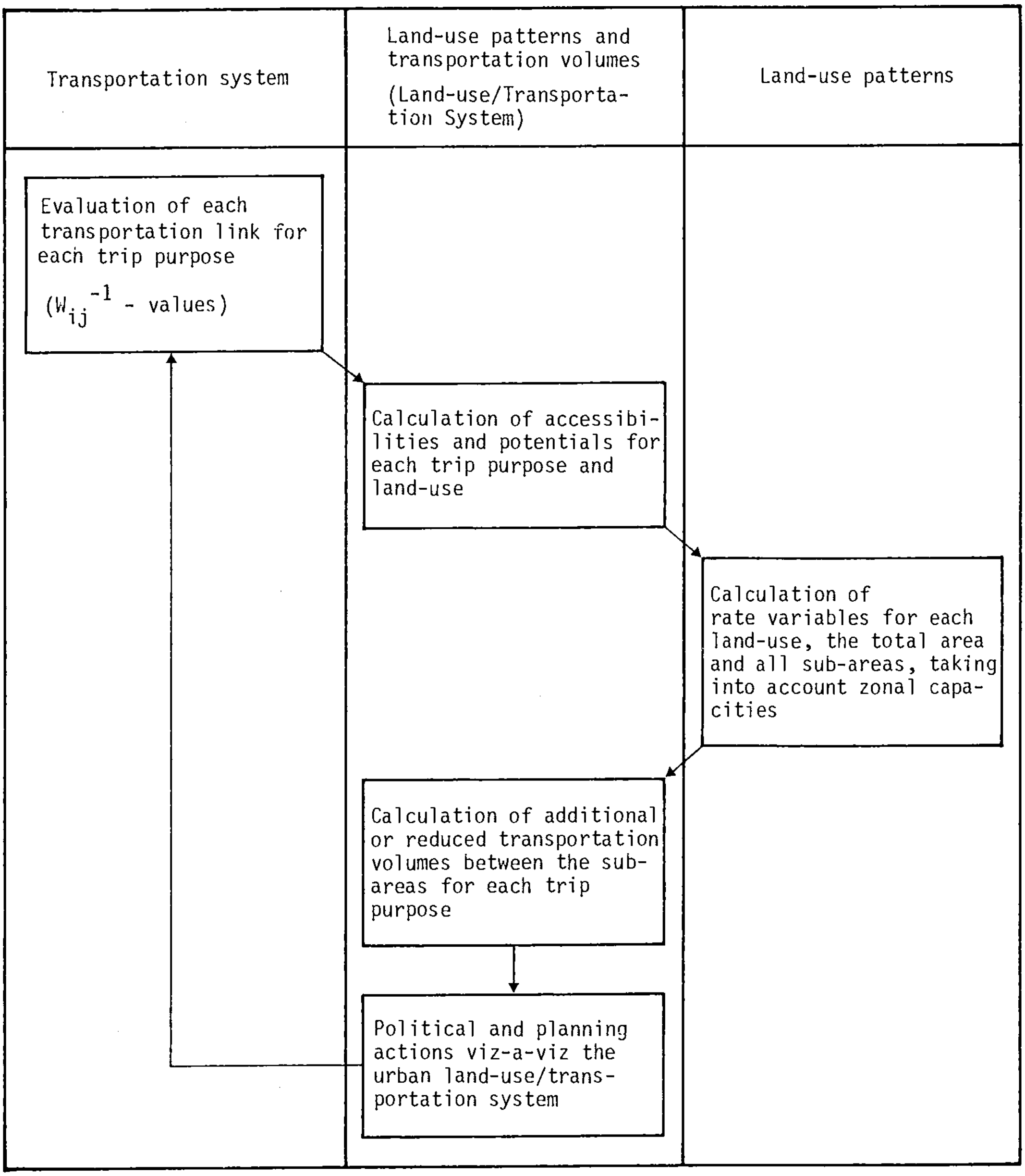


Fig. 10 – General schematic of model sequence

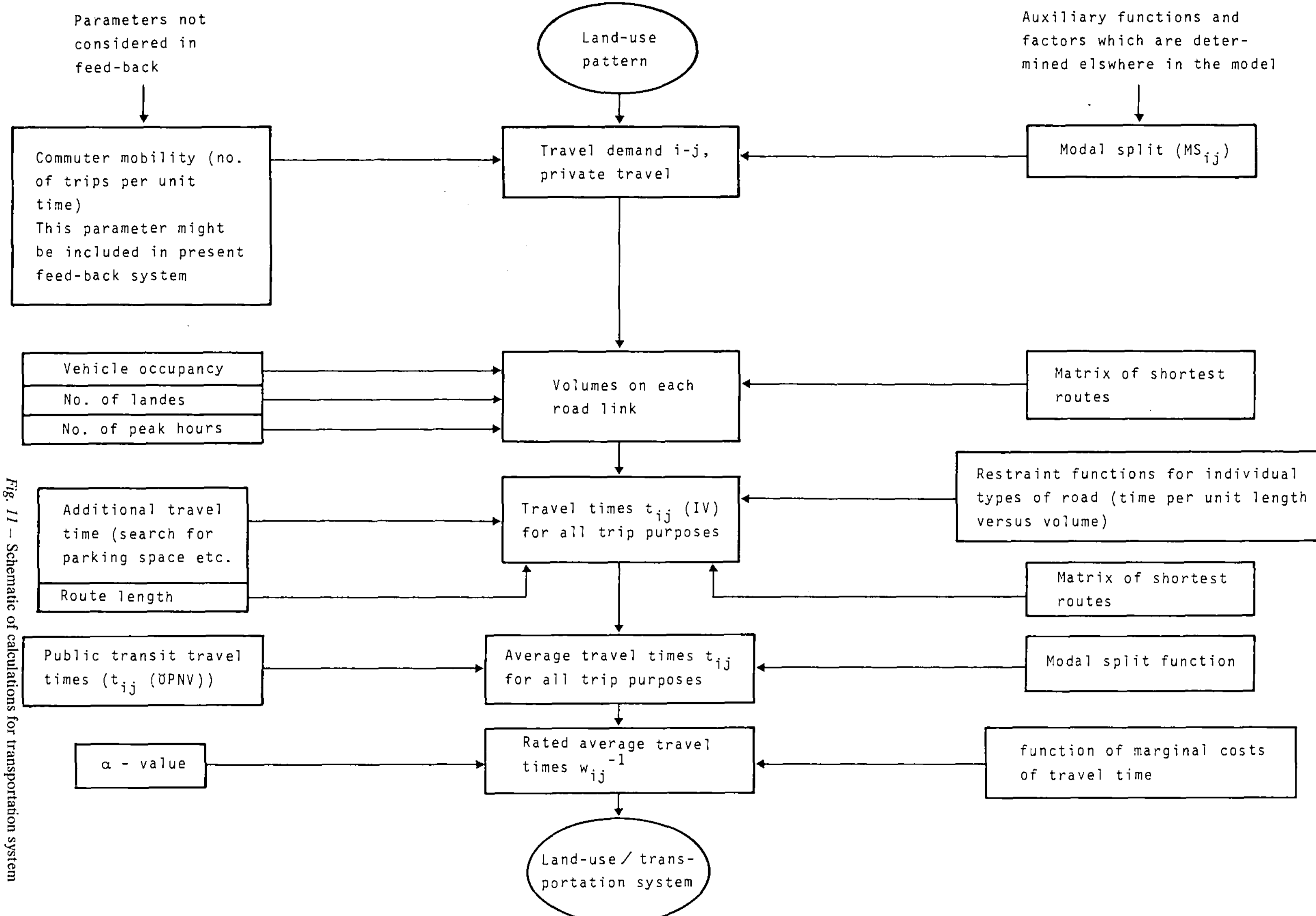


Fig. 11 – Schematic of calculations for transportation system

Next, let us have a look at the general model sequence.

1. In a first step, the individual transportation links between the sub-areas are evaluated for each trip purpose. The value factors w_{ij}^{-1} are a particular function of distance.

2. By means of the value factors, we now calculate accessibility and potentials (i. e. the determing factors) for each trip purpose and land-use. A more detailed and closer mathematical description would be too extensive here.

3. In a third step, the rate variables for each land-use, the total urban area and each sub-area may be determined while considering area capacities. The required hypothetical interconnections, have been explained above.

4. From the new quantities of land-use, which were determined by overall balancing, the additional or reduced quantities of transportation demand between the sub-areas can be estimated for each trip purpose. This is done by LEONTIEF's multi-regional input-output model, which is based on a concept of gravitation.

5. In a fifth step, there is the possibility to introduce political and planning interference into the land-use/transportation system. This can be done on the basis of the results obtained in steps 1-4. After this, a simulation period (e. g. one year) is terminated, and one may start again with step 1 (evaluation of transportation links) for the next period.

A closer observation of step 1 (evaluation of transportation links) shows the necessary parameters and supplemental functions which are not or only partially integrated into the feedback procedure. For the greater part, these are subject to changes in the course of political and planning interference into the system. Among these are: the commuter mobility, public-transport travel times, additional travel times, e. g. for finding a parking space etc., number of lanes of a given type of urban roads, number of passengers per automobile, number of peak-hours per given trip purpose (in this context, staggering of work hours comes into play) and last not least the parameter, α, of the deterrence function. Another function relates to modal split; this is, however, partially integrated into the feedback-process, since it depends on automobile travel times.

The actions mentioned in connection with step 5, however, not only relate to transportation but also to direct measures aimed at influencing urban growth and distribution of land-uses. Thus direct influences can be exerted on the parameters of the rate variables, e.g. on mobility in relation to land-uses or on potential displacements. In addition, land-use policies may be introduced to correct the distribution of land-uses generated by the determining factors, or to control total growth.

Our next task is now, to find out how urban development proceeds on the basis of the simulation model. Doing this, we are able to examine the effect of certain measures, i. e. parameter changes. Criteria for this are individual accessibilities as well as the non-weighted total and total accessibilities weighted by the area factors. Unweighted total accessibility indicates the qualitative development of the exchange situation within the urban area; weighted total accessibility indicates growth potential of individual urban land-uses. To facilitate the analysis, a so-called entropy-factor is introduced which indicates the degree of concentration or deconcentration of the land-uses. The entropy-factor, may also adopt values between 0 and 1, value 1 signalling the highest concentration of a certain land-use which is weighted by its accessibility.

For the simulation there are the following requirements:

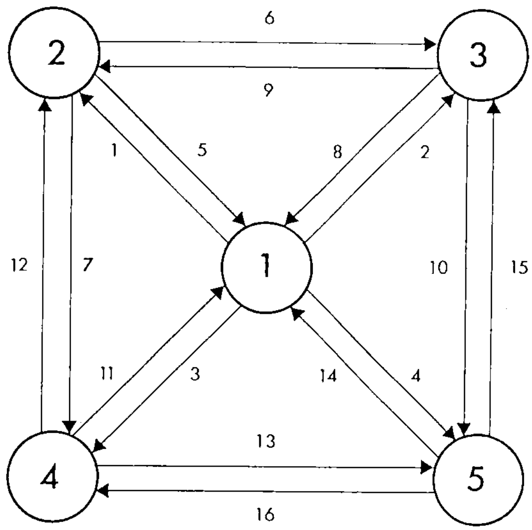


Fig. 12 – Schematic of land-use / transportation system used in test examples

We assume a fictitious land-use/transportation system including 5 sub-areas, a city centre and four decentralized sub-areas (sub-centres). Thus, we have a monocentric urban region, i.e. there is only one dominating city centre.

Not counting internal relations, the 5 sub-areas imply 20 possible relations for which 16 links of the transportation network are available. Among these, there are eight tangential links, which directly interconnect the sub-centres and 8 radial links, which lead to or away from the city centre.

Two land-uses are distributed over the sub-areas – residential and workplaces – which are connected by one relation, e.g. home-to-work commuting and v. v. With reference to the exchange process, workplaces are supply land-use (if offers places of work) residential land-use represents demand (for workplaces).

The initial situation for the simulation is as follows: As in all simulations, the level variables must have initial values. We assume, that both land-uses show a relatively high concentration, but that the concentration of workplaces is considerably higher.

The area capacities are such that there will soon be a shortage of land in the city centre, whereas there are sufficient land reserves in the sub-centres. Zoning in the city centre corresponds to the initial occupation.

Now the parameters for the calculation of the rate variables must be defined. Considering displacement, we assume, that the workplaces are the socially stronger land-use type. When land-occupancy in the city centre reaches .87, displacement in the city centre begins.

For the spatial relations among the sub-areas, the modal split ratio (it is not yet integrated into the feedback-process) and the value factor, α, for the travel time must be determined. In the first example, α, has been assigned a relatively large value, i.e. there is little resistance against covering large distances. This means, that spatial restrictions against the division of labour are small, the dynamic of the system and with this, growth, are, however, very high. Next there are statements concerning the above parameters of transportation demand, transportation supply and land-use programs. We assume that there are no land-use programs, i.e. no additional interferences into the system on the part of the government.

Finally, statements are required concerning the simulation period and the reaction time following changes in the system structure, the so-called time-lag. The simulation period is 20 years, the time-lag is 7 years.

Results of the simulation and interferences into the system

With the initial conditions as described above, the first simulation run yields the following result:

Considering total accessibilities, weighted with the area factors, there are four phases of development. (X = workplaces, ☆ = residential land-use, 0 = average of workplaces and residential land-use, which for the purpose of simplifying the test examples also represents total growth):

1. The phase prior to displacement, i. e. prior to the intensified deconcentration of residential land-use. During this phase, the extension of workplaces is restricted as their share of land in the city centre has been utilized. Unweighted total accessibility remains relatively high, since there are sufficiently large transport capacities.

2. The phase of intense deconcentration of residential land-use due to start of displacement. As more decentralized areas become involved in the exchange process, there is an increase in the chance of growth, i.e. the weighted total accessibility of residential land-use.

Through displacement, workplaces can compensate for their loss of growth potential.

Although volumes on the radial transportation links increase, there is, on the whole, no major reduction in total accessibility as yet.

Phase 2 is characterized by the fact, that additional area potential temporarily safeguards the further growth of residential land-use (at the periphery) and of workplaces (through displacement).

3. During the third phase of development, the advantages of a larger land supply at the periphery are to a certain extent diminished because of growing volumes on the radial links. Weighted total accessibility is reduced more. In addition to growing volume-capacity ratios on the transportation links, increasing area restrictions against workplaces in the city centre may come into play as soon as further displacement of residential land-use is no longer possible. As regards workplaces, we notice a higher loss in growth potential. The reason for this is the extremly long time-lag. A delayed response to structural changes results in excessive growth in favour on the city centre, thus prolonging the phase of structural redesign.

Therefore phase 3 is characterized by the fact, that a future structural redesign is being prepared, i.e. the deconcentration of workplaces, in order to escape from restrictions in both land-use and transportation capacities. The entropy curve shows how abruptly the spatial restructing is being initiated.

4. The preparations for restructuring during phase 3 now enable a regeneration of accessibilities as well as of chances of growth, i. e. of the total accessibilities weighted with area factors. We denote this development period as regeneration phase during which the exchange process increasingly moves to the tangents of the urban system, where there are still sufficient area and transportation capacities.

If one assumes a higher deterrence of distance, i. e. larger spatial restrictions against interchange, the four phases of development cannot be so easily distinguished. There is not such an intense restructuring, in particular, phase 3 blends fairly direct into the regeneration phase (4). Displacement of residential land-use is also considerably smaller. This is, however, done at the expense of reduced growth, i. e. a lesser system dynamic.

Going back to the example based on low sensitiveness to distance, we shall now examine some measures which might be employed to prevent losses of accessibility and growth.

Firstly, transportation supply on the radials is improved, at the beginning of phase 3 (year 10) by increasing the modal split ratio from .333 to .5.

The consequence is, that losses of accessibility (cf. unweighted total accessibility) can be reduced over an extended period of time. This, however, prevents an early preparation of restructuring in favour of workplaces in the sub-centres, i. e. displacement in phase 2 will be strongly intensified, so that in year 13, when further displacement is no longer possible, area restrictions for workplaces come into full effect: Major losses of growth are unavoidable. Preventing one early negative feedback (congestion on the transportation links) has initiated another negative feedback (area restriction) at an earlier stage and with much greater intensity.

Now one might think of additionally increasing the area within the city centre (from 100.000 to 150.000) in the year 13. The consequences are disastrous. The measure relatively quickly leads to another strong reduction of accessibilities and growth potentials since a further concentration of workplaces in the city centre rapidly absorbs the additional radial transportation capacities.

Instead of enlarging the central area, one could initiate a land-use program (along with increasing the modal split ratio) which would influence, beginning with the year 10, the distribution of workplaces in favour of the sub-centres.

The result shows that, although losses in growth potential are being reduced, from year 15 onwards another major drop in the Unweighted total accessibilities cannot be avoided, since total growth will be higher: A new negative feedback of the system in terms of volumes versus the existing transportation capacities. The negative feedback will have an even stranger effect on area restrictions against workplaces in the city centre, with the result that, in year 14, the weighted total accessibility will again decrease, once displacement of residential land-use is no longer possible.

To avoid this negative feedback, let us now try to exercise an additional influence on migration of city-centre workplaces, and on the timelag. Increasing migration of city-centre workplaces aims at launching an early deconcentration of workplaces (in phase 2 already), while shortening the time-lag (from 7 to 2 years) intens an early adjustment to changing realities and thus a reduction of overall growth. Both measures relieve the city centre. Since despite or even because of these measures overall growth might again be too large, involving new negative feedback effects, there will also be a restrictive policy concerning overall growth from year 10 onwards. The result shows, that now the most important negative feedbacks of the system have been eliminated: phase 3 merges continuously into regeneration phase 4. The entropy curve shows the continuous deconcentration of workplaces (weighted by accessibility). We have outwitted the system.

The example proved that, with the help of appropriate interferences into the urban system, major losses of accessibility and growth may be avoided. Individual measures alone, however, are insufficient; it is imperative to employ whole packets of measures, where the individual components offset the negative feedback of others, i. e. where all measures are carefully coordinated. This is a basic concept, which was already distinctly emphasized by Forrester.

The examples, however, also show that measures are required which, in our economic and social system are difficult to implement i.e. for which there is no political means. In this context, I venture to say that we are confronted with a barbarian form of society which, is capable of constructing and using sub-ways and other modern means of transport, but unable to exert a purposeful influence on mobility and growth and other social and economic phenomena of our time.

It has now been attempted to calibrate the model for forecasting purposes on the basis of development data for the city of Zurich between 1955 and 1965. The result of this forecast for the individual sub-areas – measured by the deviation of calculated from actual development after a period of 10 years – (viz. Fig. 20-23) is not yet fully satisfactory. Several reasons are responsible for this: insufficient data basis, inappropriate zoning, missing variables of influence, a partly too high degree of aggregation for the variables used, a too small number of interrelations considered (job and retail commuters only), defective model construction. Should it be possible to work out the required modifications and to improve the data basis, more reliable forecasting can be achieved in the future.

ENTROPY AND TOTAL ACCESSIBILITY | TEST EXAMPLE NO. 5 | FIG. 13

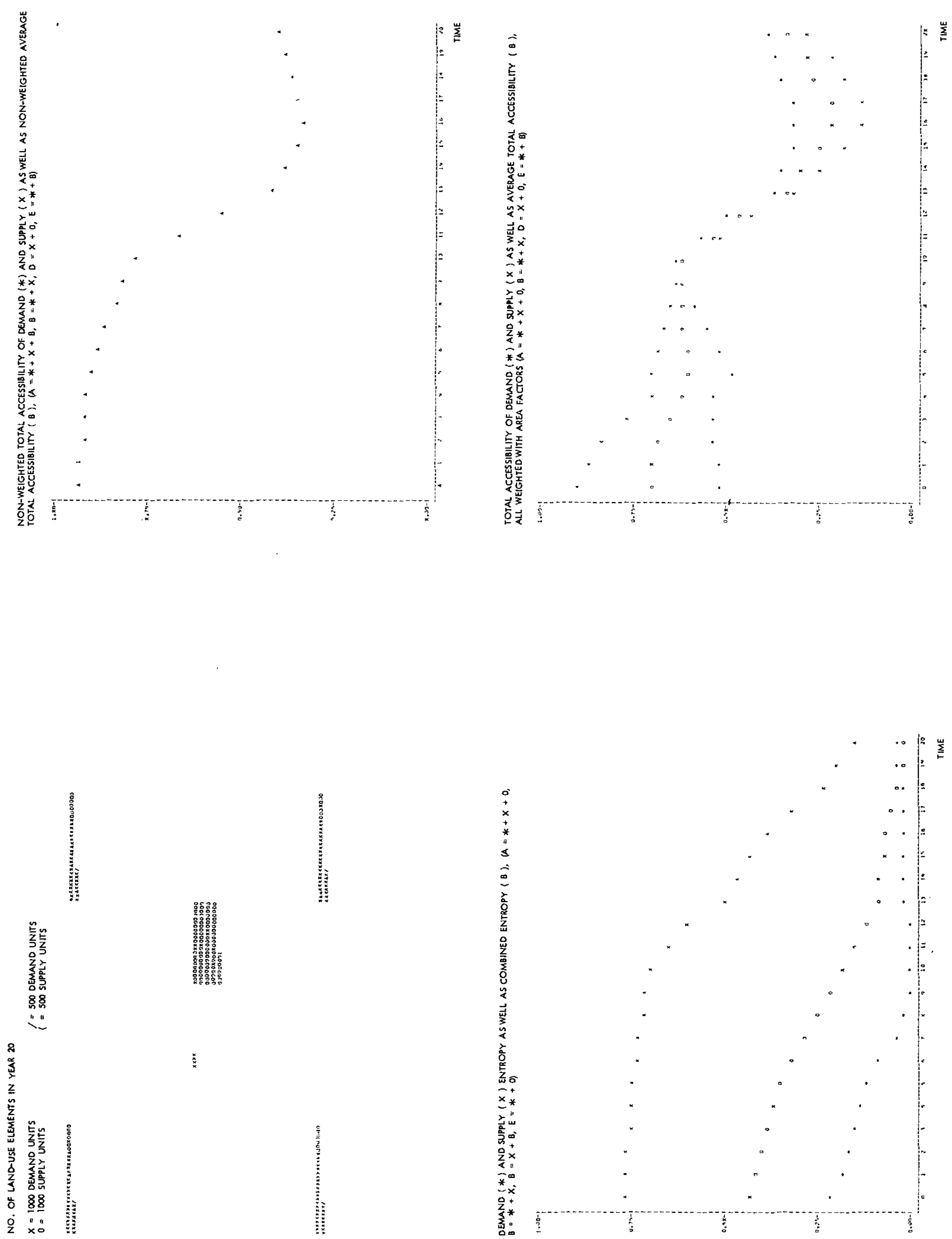


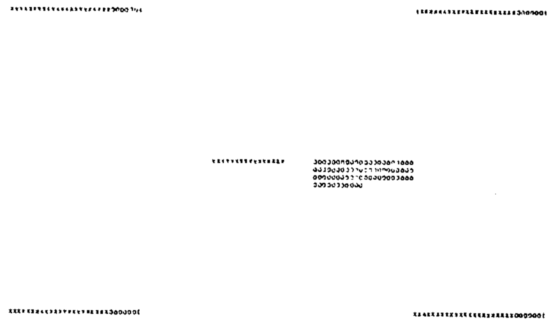
Fig. 13

Fig. 14

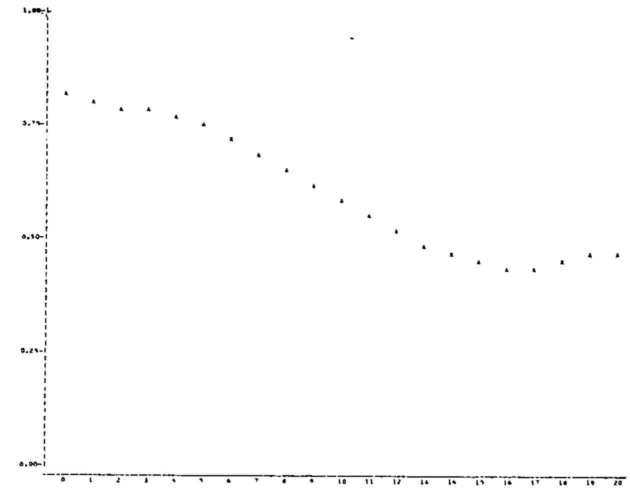
NO. OF LAND-USE ELEMENTS IN YEAR 20

X = 1000 DEMAND UNITS
0 = 1000 SUPPLY UNITS

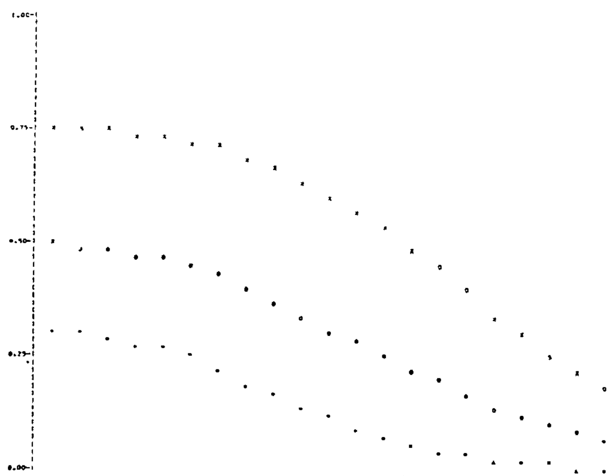
= 500 DEMAND UNITS
= 500 SUPPLY UNITS



NON-WEIGHTED TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS NON-WEIGHTED AVERAGE TOTAL ACCESSIBILITY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



DEMAND (*) AND SUPPLY (X) ENTROPY AS WELL AS COMBINED ENTROPY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS AVERAGE TOTAL ACCESSIBILITY (0), ALL WEIGHTED WITH AREA FACTORS (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)

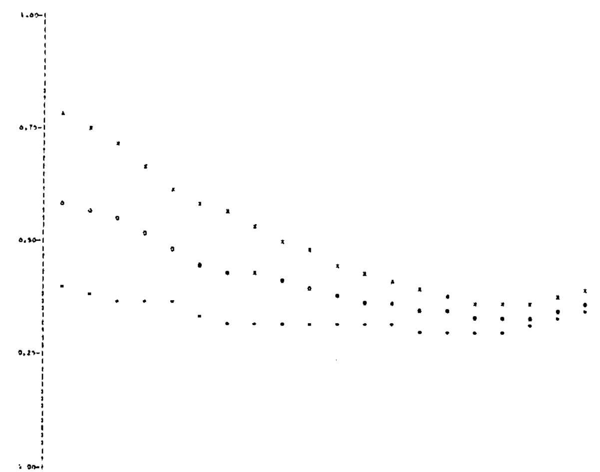
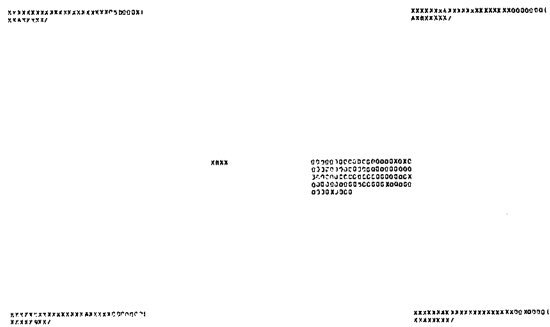


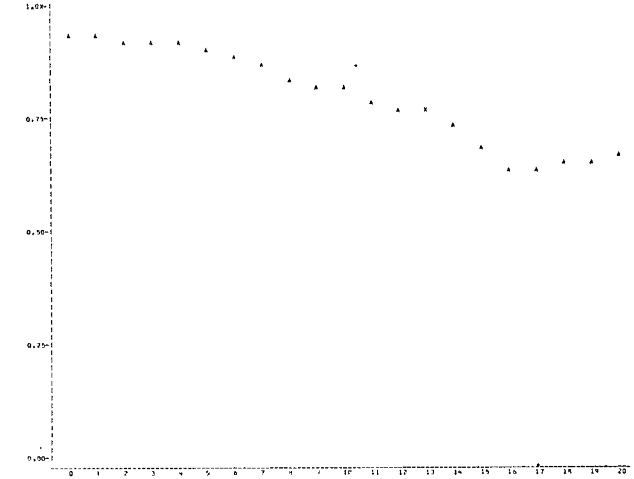
Fig. 15

NO. OF LAND-USE ELEMENTS IN YEAR 20

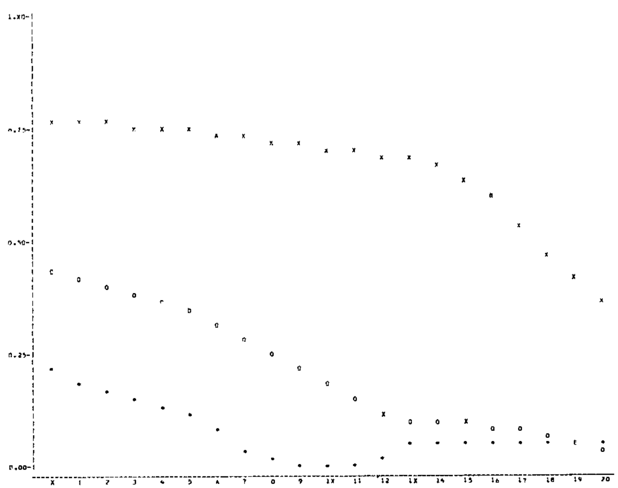
X = 1000 DEMAND UNITS / = 500 DEMAND UNITS
0 = 1000 SUPPLY UNITS (= 500 SUPPLY UNITS



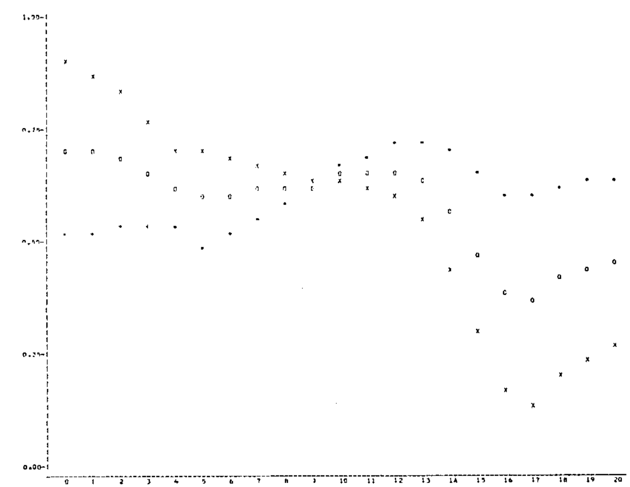
NON-WEIGHTED TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS NON-WEIGHTED AVERAGE TOTAL ACCESSIBILITY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



DEMAND (*) AND SUPPLY (X) ENTROPY AS WELL AS COMBINED ENTROPY (0), (A = * + X + 0, 0 = * + X, D = X + 0, E = * + 0)

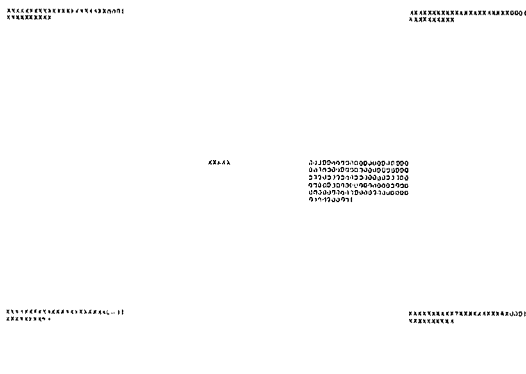


TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS AVERAGE TOTAL ACCESSIBILITY (0), ALL WEIGHTED WITH AREA FACTORS (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)

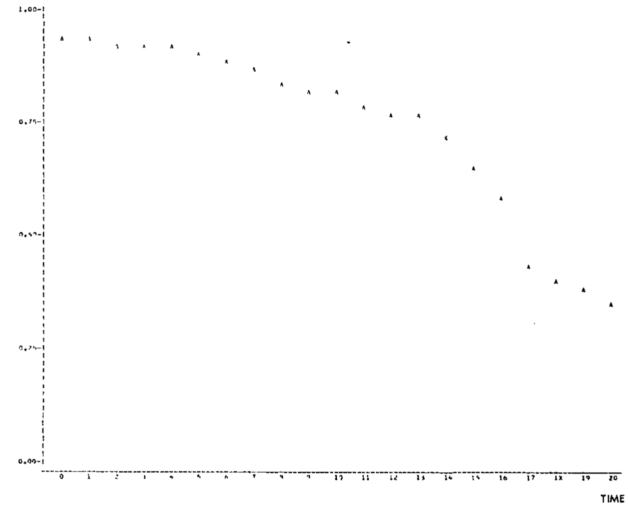


NO. OF LAND-USE ELEMENTS IN YEAR 20

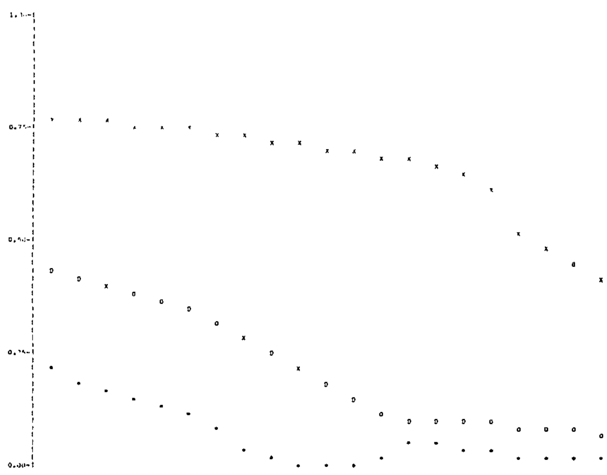
X = 1000 DEMAND UNITS
0 = 1000 SUPPLY UNITS
/ = 500 DEMAND UNITS
(= 500 SUPPLY UNITS



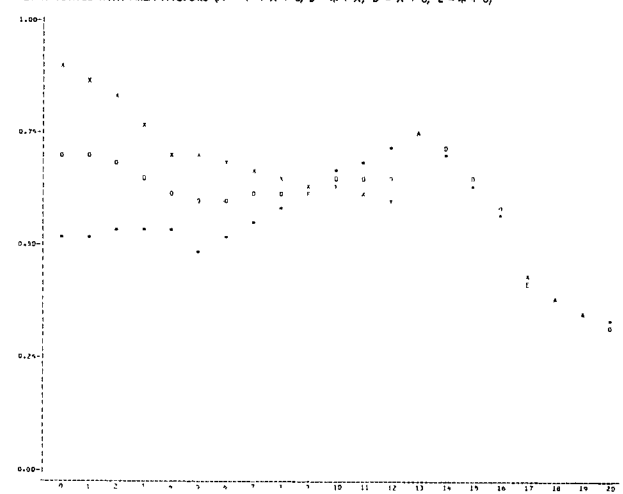
NON-WEIGHTED TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS NON-WEIGHTED AVERAGE TOTAL ACCESSIBILITY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



DEMAND (*) AND SUPPLY (X) ENTROPY AS WELL AS COMBINED ENTROPY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



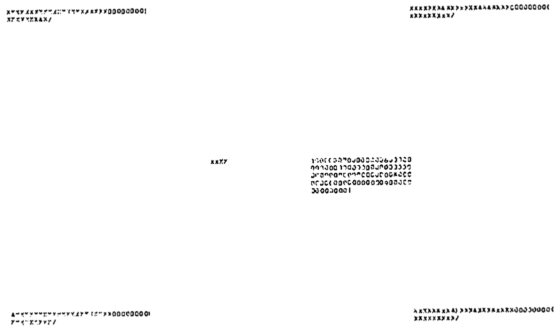
TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS AVERAGE TOTAL ACCESSIBILITY (0), ALL WEIGHTED WITH AREA FACTORS (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



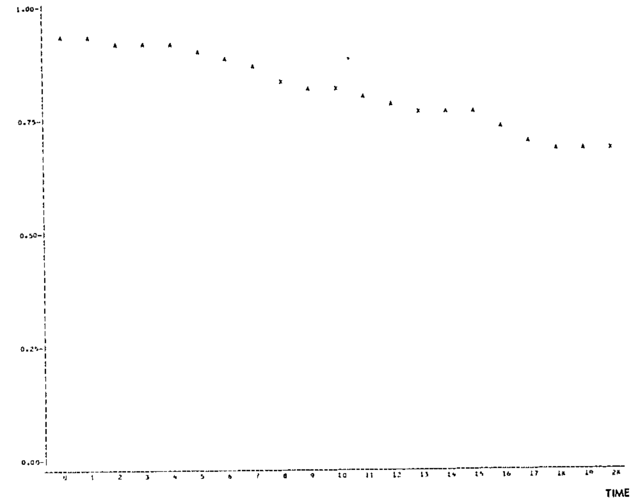
ENTROPY AND TOTAL ACCESSIBILITY | TEST EXAMPLE NO. 10 | FIG. 17

NO. OF LAND-USE ELEMENTS IN YEAR 20

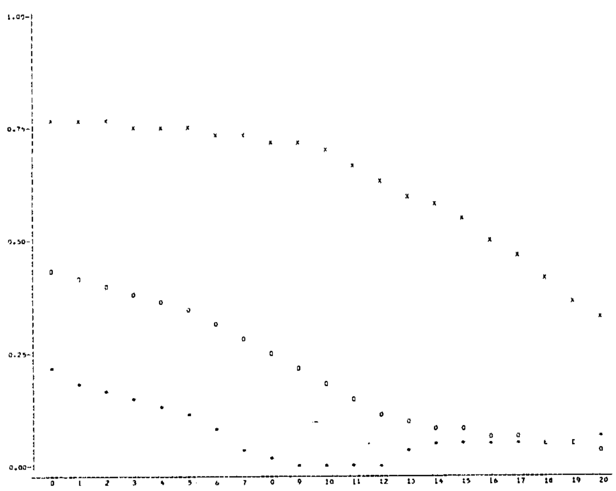
X = 1000 DEMAND UNITS / = 500 DEMAND UNITS
0 = 1000 SUPPLY UNITS (= 500 SUPPLY UNITS



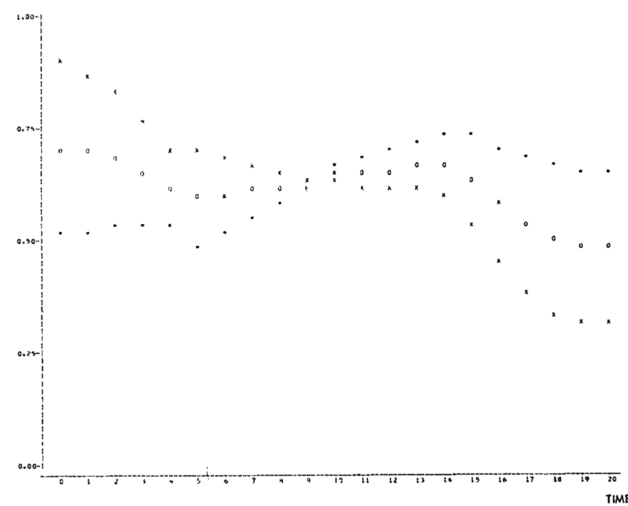
NON-WEIGHTED TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS NON-WEIGHTED AVERAGE TOTAL ACCESSIBILITY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



DEMAND (*) AND SUPPLY (X) ENTROPY AS WELL AS COMBINED ENTROPY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



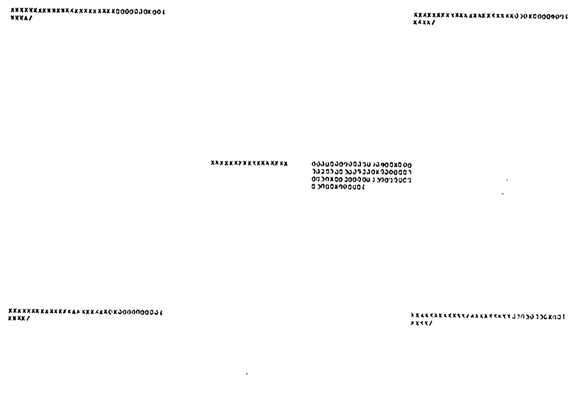
TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS AVERAGE TOTAL ACCESSIBILITY (0), ALL WEIGHTED WITH AREA FACTORS (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



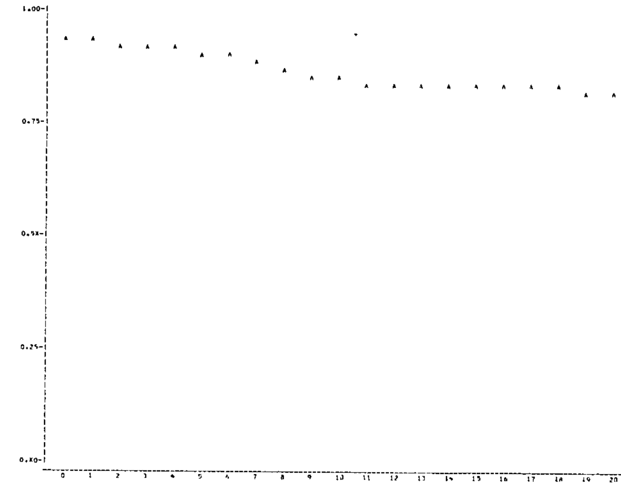
ENTROPY AND TOTAL ACCESSIBILITY | TEST EXAMPLE NO. 16 | FIG. 18

NO. OF LAND-USE ELEMENTS IN YEAR 20

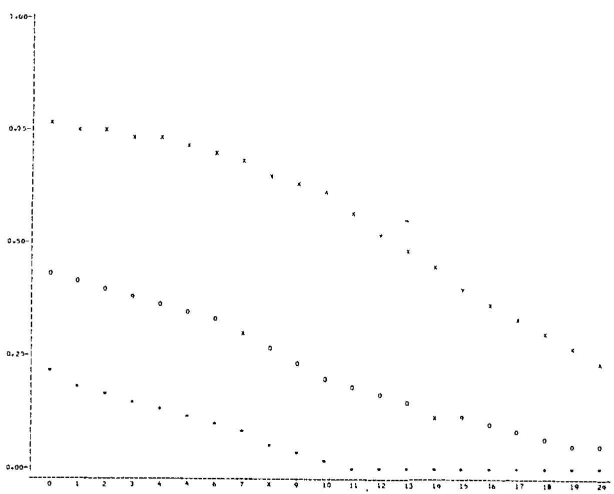
X = 1000 DEMAND UNITS / = 500 DEMAND UNITS
0 = 1000 SUPPLY UNITS (= 500 SUPPLY UNITS



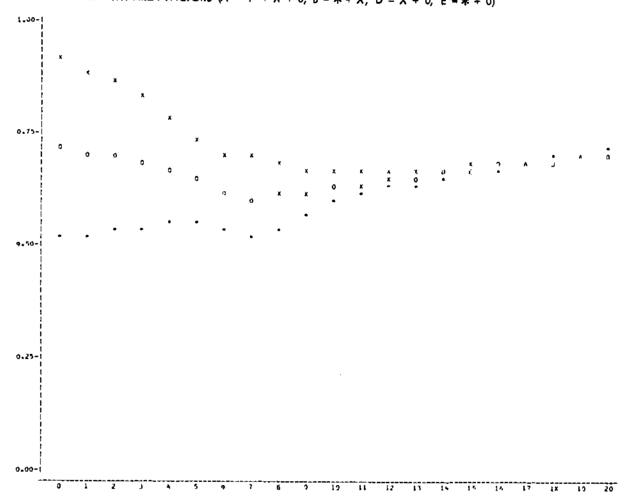
NON-WEIGHTED TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS NON-WEIGHTED AVERAGE TOTAL ACCESSIBILITY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



DEMAND (*) AND SUPPLY (X) ENTROPY AS WELL AS COMBINED ENTROPY (0), (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



TOTAL ACCESSIBILITY OF DEMAND (*) AND SUPPLY (X) AS WELL AS AVERAGE TOTAL ACCESSIBILITY (0), ALL WEIGHTED WITH AREA FACTORS (A = * + X + 0, B = * + X, D = X + 0, E = * + 0)



Residential land-use, year 10

Zone	Available in year 0	Available	Ind[3]	Growth / Decrease	Positive migration	Negative migration	Displacement	Natural development	Accessibility	Potential	Area factor	Land-occupancy [%]
1	52513	43868	10	-395	7569	7591	390	8	0.891	0.707	0.953	28.91
2	31966	31026	4	-338	5206	5236	339	29	0.900	0.674	0.936	45.34
3	21480	23491	0	0	2947	2971	0	124	0.788	0.674	0.755	77.95
4	3909	11300	0	0	1491	1508	0	16	0.748	0.621	0.945	92.05
5	46264	44415	10	-285	6622	6639	285	76	0.867	0.663	0.913	61.95
6	67782	67545	8	-450	10953	10934	450	-18	0.907	0.663	0.927	74.55
7	26109	25155	5	-318	4439	4450	319	11	0.359	0.655	0.935	62.60
8	37111	35788	7	-275	6423	6335	275	-79	0.846	0.651	0.940	64.57
9	2698	7103	0	674	1489	894	0	69	0.716	0.346	0.967	89.58
10	25303	34891	0	0	4585	5193	0	613	0.671	0.520	0.720	88.73
11	35523	43278	2	-72	6535	6890	72	356	0.919	0.531	0.937	60.21
12	23140	41823	0	1075	6273	5324	0	605	0.608	0.525	0.703	85.90
13	33453	48830	0	0	7343	7929	0	495	0.812	0.590	0.943	65.79
14	20053	32366	0	1104	5367	4490	0	227	0.690	0.370	0.927	78.00
15	3729	17247	0	379	3041	2380	0	318	0.673	0.374	0.272	86.00
16	10200	15168	0	393	2237	1391	0	143	0.741	0.273	0.202	65.00
17	14376	22840	0	1101	3613	2930	0	313	0.743	0.130	0.903	69.00
18	6678	13210	0	583	2469	1790	0	204	0.685	0.120	0.966	75.00
19	6689	12109	0	681	2075	1591	0	193	0.721	0.233	0.923	74.00
20	1454	2734	0	192	526	369	0	34	0.687	0.296	0.994	91.00
21	2402	5116	0	413	1011	650	0	52	0.720	0.412	0.903	96.00
22	7323	9693	0	370	1632	1391	0	139	0.669	0.205	0.973	78.00
23	1916	2664	0	120	474	407	0	53	0.626	0.341	0.993	78.00
24	7503	10316	0	324	1913	1704	0	115	0.761	0.429	0.928	61.00
25	9907	16720	0	903	2897	2364	0	370	0.469	0.316	0.944	75.00
26	3275	6382	0	443	1168	905	0	170	0.661	0.243	0.994	90.00
27	701	1841	0	171	367	219	0	22	0.757	0.233	0.993	77.00
28	30003	42438	0	1022	6926	6501	0	536	0.636	0.172	0.979	66.00
29	4598	5990	0	244	1037	229	0	127	0.626	0.364	0.997	87.00
30	2033	4595	0	372	969	573	0	91	0.727	0.345	1.000	63.00
31	1661	4576	0	373	979	566	0	90	0.722	0.233	0.963	77.00
32	2769	4112	0	239	741	559	0	55	0.696	0.311	0.903	78.00
33	1866	3754	0	267	634	516	0	93	0.674	0.413	0.937	62.00
34	6918	13766	0	345	2414	1325	0	256	0.705	0.210	0.921	74.00
35	9609	21144	0	1453	2747	2790	0	474	0.702	0.295	0.902	63.00
36	7363	14080	0	352	2596	1931	0	176	0.716	0.401	0.973	65.00
37	2652	5031	0	345	915	663	0	93	0.705	0.324	0.593	81.00
38	3572	20668	0	1792	3300	2541	0	464	0.733	0.416	0.989	72.00
39	5034	10061	0	714	1969	1344	0	130	0.682	0.288	0.971	75.00
40	2745	4936	0	329	910	696	0	105	0.667	0.356	1.000	75.00
41	13421	23285	0	1334	3940	3033	0	337	0.714	0.257	0.963	72.00
42	947	2056	0	190	425	261	0	26	0.703	0.353	1.000	88.00
43	8166	20519	0	1302	4153	2426	0	175	0.762	0.507	0.962	95.00
44	14431	29680	0	1553	5150	3725	0	123	0.723	0.373	0.925	79.00
45	2497	5090	0	384	1001	633	0	73	0.677	0.275	0.965	82.00
46	12777	17172	0	323	2573	2398	0	137	0.706	0.230	0.727	72.00
47	7716	12151	0	611	2144	1693	0	150	0.682	0.154	0.854	77.00
48	9968	13575	0	526	2030	1921	0	219	0.703	0.112	0.636	70.00
G	673222	904995	0	22414	171175[1]	10933[1]	-	8553	0.767	-	0.650[2]	-

1) employees
2) total accessibility, weighted with area factors
3) no. of years of negative development

Retail land-use, year 10

Zone	Available in year 0	Available	Ind[3]	Growth / Decrease	Positive migration	Negative migration	Displacement	Natural development	Accessibility	Potential	Area factor	Land-occupancy [%]
1	22370	37264	0	417	1708	1291	0	-	0.708	0.570	0.551	25.93
2	6193	10015	0	276	583	307	0	-	0.786	0.620	0.633	15.60
3	1465	2150	0	7	71	64	0	-	0.834	0.553	0.312	7.13
4	228	456	0	32	43	12	0	-	0.883	0.590	0.957	4.74
5	4193	6557	0	222	409	187	0	-	0.841	0.637	0.694	9.69
6	5656	8209	0	283	521	237	0	-	0.930	0.652	0.704	9.60
7	4431	6901	0	193	404	211	0	-	0.789	0.625	0.642	14.16
8	5277	6923	0	193	403	210	0	-	0.795	0.615	0.612	13.13
9	124	252	0	19	25	6	0	-	0.931	0.556	0.934	3.90
10	785	1536	0	107	146	33	0	-	0.899	0.576	0.232	4.86
11	3027	5433	0	287	439	152	0	-	0.941	0.604	0.736	8.13
12	1143	2199	0	144	200	57	0	-	0.909	0.574	0.535	5.13
13	2654	4815	0	370	404	134	0	-	0.938	0.593	0.911	7.32
14	1636	2029	0	7	66	59	0	-	0.865	0.444	0.306	4.00
15	595	1146	0	79	109	30	0	-	0.907	0.442	0.961	5.00
16	782	1325	0	63	101	37	0	-	0.839	0.350	0.762	6.00
17	1470	2380	0	115	104	69	0	-	0.818	0.244	0.932	7.00
18	611	1051	0	62	91	33	0	-	0.956	0.171	0.924	6.00
19	642	1146	0	67	99	31	0	-	0.369	0.336	0.939	7.00
20	116	225	0	16	22	6	0	-	0.890	0.371	0.994	5.00
21	178	335	0	18	27	3	0	-	0.901	0.495	0.207	3.00
22	625	954	0	34	63	29	0	-	0.810	0.333	0.673	5.00
23	94	172	0	11	16	5	0	-	0.935	0.409	1.000	5.00
24	581	1036	0	59	88	23	0	-	0.834	0.496	0.986	6.00
25	641	1178	0	77	109	32	0	-	0.958	0.397	0.933	7.00
26	204	391	0	27	37	10	0	-	0.882	0.316	0.937	4.00
27	64	124	0	9	12	3	0	-	0.897	0.311	0.975	4.00
28	3669	4924	0	161	336	175	0	-	0.683	0.239	0.837	7.00
29	226	415	0	25	37	12	0	-	0.839	0.463	0.943	2.00
30	191	374	0	27	36	10	0	-	0.896	0.451	1.000	5.00
31	172	335	0	24	32	9	0	-	0.939	0.323	0.971	6.00
32	185	352	0	24	33	9	0	-	0.970	0.403	0.933	4.00
33	96	180	0	12	17	5	0	-	0.970	0.513	1.000	6.00
34	617	1095	0	65	94	23	0	-	0.873	0.299	0.369	5.00
35	1867	2943	0	151	244	93	0	-	0.752	0.403	1.000	14.00
36	706	1281	0	83	119	35	0	-	0.355	0.507	0.995	6.00
37	223	436	0	31	42	11	0	-	0.901	0.427	0.395	5.00
38	805	1539	0	110	149	40	0	-	0.902	0.516	0.994	6.00
39	405	740	0	49	69	20	0	-	0.965	0.390	0.985	5.00
40	153	291	0	20	28	3	0	-	0.874	0.495	1.000	4.00
41	1233	2063	0	111	171	60	0	-	0.915	0.363	0.995	6.00
42	73	147	0	11	15	4	0	-	0.917	0.443	1.000	4.00
43	876	1520	0	57	95	42	0	-	0.879	0.551	0.493	5.00
44	1527	2662	0	134	208	74	0	-	0.855	0.449	0.259	7.00
45	289	471	0	26	40	14	0	-	0.785	0.213	0.984	7.00
46	1282	1716	0	40	92	57	0	-	0.937	0.270	0.555	6.00
47	665	1116	0	60	92	32	0	-	0.630	0.274	0.821	7.00
48	1336	1755	0	52	108	57	0	-	0.744	0.161	0.730	9.00
G	52439	132557	0	4361	5009	648	-	-	0.783	-	0.560[2]	-

2) total accessibility, weighted with area factors
3) no. of years of negative development

Fig. 19 – Level and changes for 4 selected land-uses in 1965 at low distance sensibility

Industrial land-use, year 10

Zone	Available in year 0	Available	Ind 3)	Growth / Decrease	Positive migration	Negative migration	Displace-ment	Natural develop-ment	Accessibility	Potential	Area factor	Land-occupancy [%]
1	29950	26842	10	-82	1426	1507	0	-	0.709	0.577	0.384	20.09
2	12946	14103	0	8	733	725	0	-	0.770	0.578	0.341	22.36
3	2370	3448	0	1	171	169	0	-	0.809	0.508	0.311	12.59
4	160	233	0	2	12	11	0	-	0.860	0.552	0.297	2.06
5	13348	15705	0	33	792	758	0	-	0.821	0.599	0.308	23.70
6	7098	6969	9	-1	340	341	0	-	0.811	0.621	0.306	9.27
7	1842	2172	0	5	109	105	0	-	0.820	0.595	0.309	5.99
8	5949	7008	0	19	362	343	0	-	0.810	0.588	0.319	13.90
9	89	252	0	23	33	10	0	-	0.913	0.529	0.768	3.92
10	1279	1759	0	16	96	80	0	-	0.868	0.548	0.308	4.83
11	14282	17673	0	109	967	859	0	-	0.816	0.574	0.333	26.36
12	1777	2993	0	71	205	135	0	-	0.871	0.545	0.375	6.97
13	18469	15347	0	206	952	745	0	-	0.808	0.542	0.373	23.33
14	4606	6033	0	89	392	294	0	-	0.811	0.386	0.369	14.00
15	1277	2134	0	59	155	95	0	-	0.872	0.395	0.435	7.00
16	3547	5303	0	152	414	262	0	-	0.786	0.295	0.501	25.00
17	4214	7262	0	337	685	348	0	-	0.796	0.202	0.611	21.00
18	1558	3038	0	205	351	146	0	-	0.776	0.144	0.810	17.00
19	1373	2706	0	151	274	123	0	-	0.829	0.253	0.633	16.00
20	153	408	0	38	55	18	0	-	0.824	0.225	0.919	12.00
21	327	701	0	40	72	31	0	-	0.844	0.431	0.610	9.00
22	1352	2225	0	90	203	113	0	-	0.755	0.241	0.624	15.00
23	237	513	0	39	65	26	0	-	0.730	0.353	0.956	15.00
24	4329	5263	0	84	367	283	0	-	0.731	0.439	0.477	30.00
25	2042	3784	0	195	378	183	0	-	0.783	0.353	0.660	15.00
26	502	1278	0	119	175	56	0	-	0.818	0.273	0.943	15.00
27	220	528	0	45	68	23	0	-	0.847	0.260	0.828	18.00
28	13401	15374	0	292	1285	992	0	-	0.609	0.180	0.715	23.00
29	496	1086	0	79	131	52	0	-	0.768	0.419	0.847	3.00
30	402	1091	0	110	156	47	0	-	0.832	0.402	0.994	30.00
31	459	1048	0	81	127	46	0	-	0.842	0.285	0.773	13.00
32	463	1178	0	106	159	53	0	-	0.798	0.368	0.946	17.00
33	393	901	0	76	119	43	0	-	0.771	0.471	0.955	23.00
34	1620	3357	0	228	381	153	0	-	0.816	0.767	0.741	19.00
35	1764	3793	0	292	473	181	0	-	0.774	0.452	0.879	12.00
36	2294	4970	0	374	610	236	0	-	0.777	0.469	0.855	27.00
37	444	1051	0	82	128	46	0	-	0.833	0.397	0.782	12.00
38	1807	4507	0	375	567	191	0	-	0.863	0.482	0.775	14.00
39	1521	2818	0	156	293	137	0	-	0.776	0.361	0.701	15.00
40	453	1168	0	113	165	52	0	-	0.806	0.460	0.992	13.00
41	4093	7267	0	332	676	344	0	-	0.807	0.330	0.589	20.00
42	83	241	0	25	35	10	0	-	0.879	0.414	0.938	7.00
43	767	1751	0	98	171	73	0	-	0.910	0.519	0.520	2.00
44	2219	3696	0	110	273	167	0	-	0.859	0.412	0.429	10.00
45	384	848	0	61	99	38	0	-	0.828	0.283	0.745	9.00
46	3420	4552	0	103	331	227	0	-	0.783	0.242	1.471	19.00
47	1731	2649	0	96	227	131	0	-	0.783	0.207	1.565	12.00
48	2431	3309	0	98	269	171	0	-	0.750	0.142	0.561	16.00
G	168654	222347	0	5341	7155	1814	-	-	0.767	-	0.357 2)	-

2) total accessibility, weighted with area factors
3) no. of years of negative development

Administrative land-use, year 10

Zone	Available in year 0	Available	Ind 3)	Growth / Decrease	Positive migration	Negative migration	Displace-ment	Natural develop-ment	Accessibility	Potential	Area factor	Land-occupancy [%]
1	31348	35088	0	467	1602	1135	0	-	0.780	0.623	0.335	25.17
2	7360	13559	0	189	507	318	0	-	0.810	0.613	0.352	16.30
3	531	667	0	0	21	20	0	-	0.919	0.563	0.220	2.27
4	76	130	3	1	5	4	0	-	0.942	0.594	0.229	1.15
5	2529	2224	0	69	163	94	0	-	0.835	0.632	0.363	4.76
6	5217	6542	0	169	361	192	0	-	0.927	0.644	0.353	7.58
7	3617	5087	0	112	260	147	0	-	0.939	0.627	0.339	23.36
8	3686	4449	0	75	237	131	0	-	0.929	0.623	0.359	9.50
9	88	235	0	20	26	6	0	-	0.876	0.557	0.706	2.75
10	413	568	0	7	19	18	0	-	0.832	0.562	0.721	1.53
11	2020	3135	0	63	157	94	0	-	0.915	0.592	0.374	4.64
12	634	923	0	3	30	27	0	-	0.544	0.559	0.270	1.34
13	1552	2453	0	14	69	75	0	-	0.907	0.569	0.343	3.50
14	555	1236	0	92	128	36	0	-	0.764	0.339	0.912	4.00
15	221	514	0	37	51	14	0	-	0.930	0.405	0.712	2.00
16	212	635	0	42	62	20	0	-	0.752	0.302	0.783	6.00
17	700	1200	0	52	80	30	0	-	0.759	0.205	0.579	3.00
18	243	471	0	30	44	15	0	-	0.756	0.147	0.765	2.00
19	277	560	0	32	49	16	0	-	0.304	0.257	0.641	3.00
20	62	146	0	11	15	4	0	-	0.812	0.327	0.775	2.00
21	133	237	0	18	27	9	0	-	0.522	0.439	0.608	3.00
22	199	343	0	15	26	11	0	-	0.744	0.749	0.592	2.00
23	49	103	0	8	11	3	0	-	0.717	0.360	0.462	2.00
24	152	325	0	25	35	10	0	-	0.737	0.451	0.326	3.00
25	194	429	0	35	43	13	0	-	0.754	0.357	0.347	3.00
26	61	141	0	12	16	4	0	-	0.770	0.271	0.323	1.00
27	13	40	0	3	4	1	0	-	0.706	0.263	0.767	1.00
28	1676	2669	0	98	204	106	0	-	0.606	0.183	0.266	4.00
29	66	150	0	13	17	5	0	-	0.744	0.416	0.937	3.00
30	93	240	0	23	29	7	0	-	0.913	0.473	0.977	2.00
31	109	265	0	22	30	3	0	-	0.900	0.278	0.837	4.00
32	50	119	0	10	13	3	0	-	0.778	0.263	0.720	1.00
33	128	278	0	22	30	9	0	-	0.743	0.467	0.225	4.00
34	285	521	0	25	40	16	0	-	0.764	0.259	0.576	2.00
35	1203	2620	0	224	307	83	0	-	0.747	0.350	0.962	11.00
36	207	468	0	37	50	14	0	-	0.772	0.465	0.264	2.00
37	85	205	0	16	22	6	0	-	0.813	0.368	0.835	2.00
38	252	661	0	66	84	19	0	-	0.936	0.470	0.327	3.00
39	158	336	0	24	35	10	0	-	0.754	0.352	0.849	2.00
40	49	119	0	11	14	3	0	-	0.777	0.457	0.999	2.00
41	457	817	0	36	62	26	0	-	0.757	0.323	0.575	2.00
42	30	78	0	6	0	2	0	-	0.958	0.414	0.761	1.00
43	331	817	0	53	75	22	0	-	0.880	0.532	0.545	3.00
44	714	1511	0	76	119	43	0	-	0.839	0.421	0.519	4.00
45	79	177	0	14	19	5	0	-	0.783	0.291	0.345	2.00
46	419	796	0	46	70	25	0	-	0.756	0.240	0.706	4.00
47	231	487	0	36	51	15	0	-	0.763	0.198	0.963	4.00
48	867	1201	0	32	73	40	0	-	[illegible]	0.135	0.495	5.00
G	69942	95055	0	2484	2954	470	-	-	0.775	-	0.388 2)	-

2) total accessibility, weighted with area factors
3) no. of years of negative development

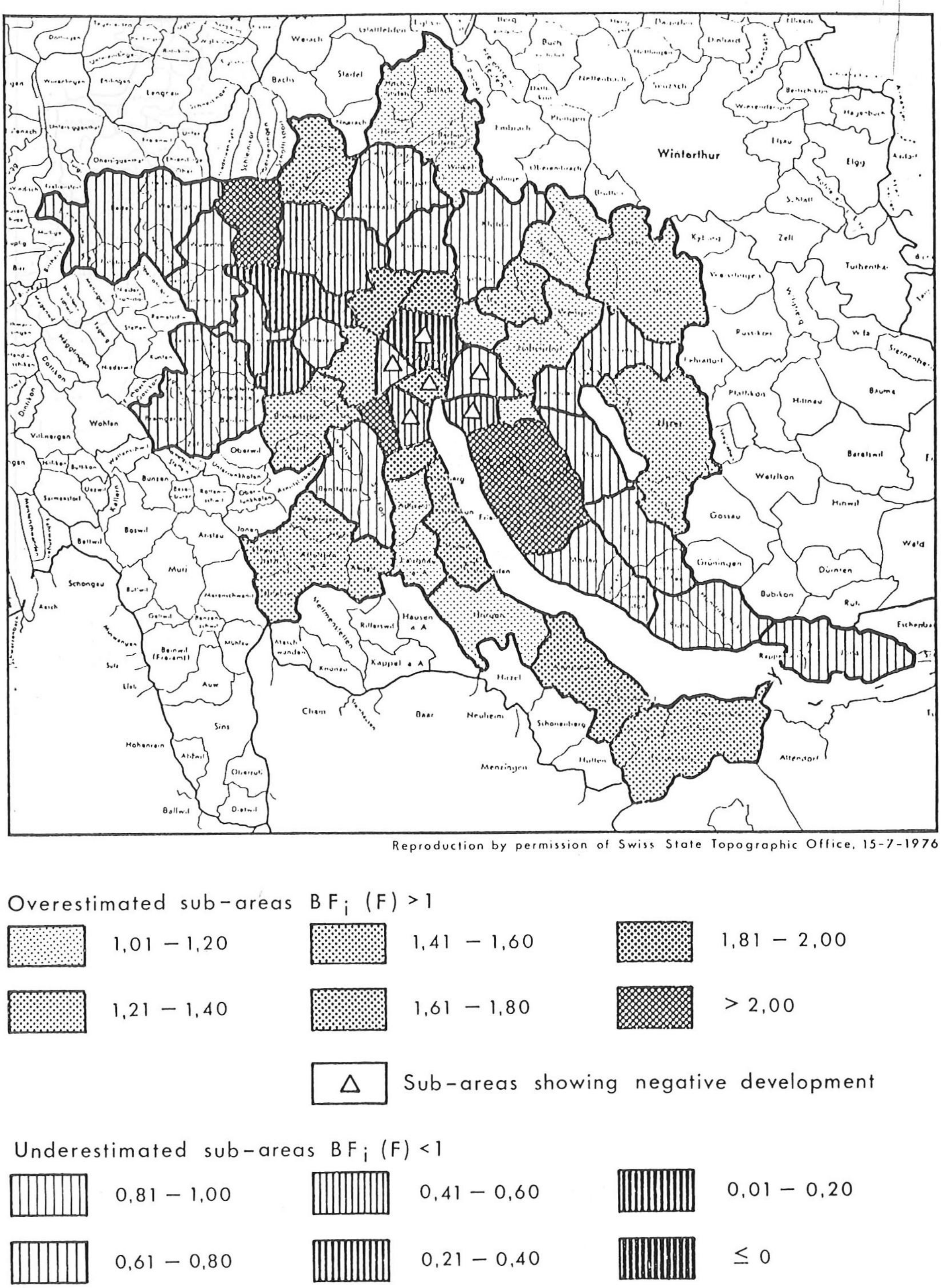


Fig. 20 – Comparison of actual and forecast development of residential land-use at low distance sensibility (Simulation 1a)

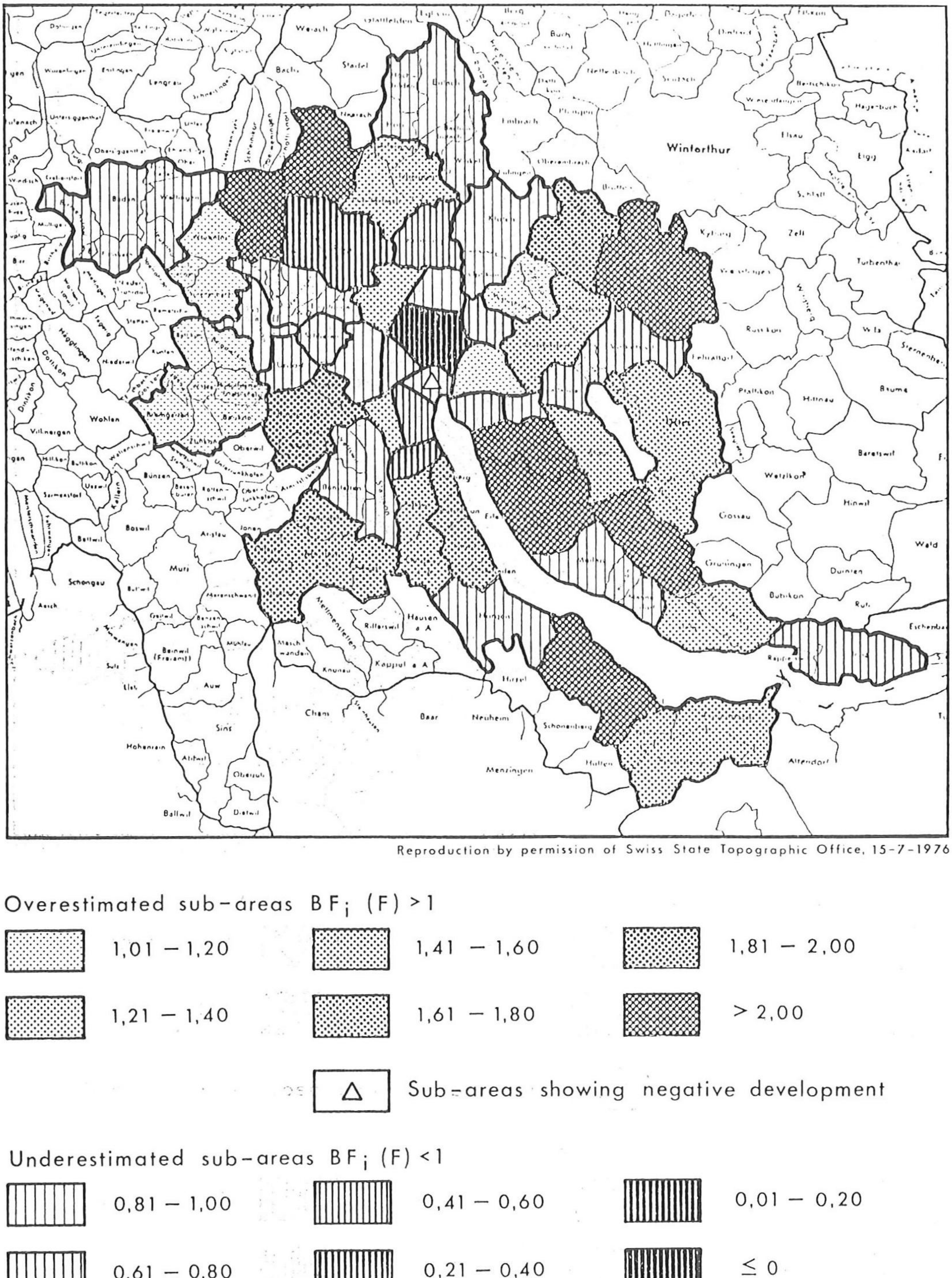


Fig. 21 – Comparison of actual and forecast development of industrial land-use at low distance sensibility (Simulation 1a)

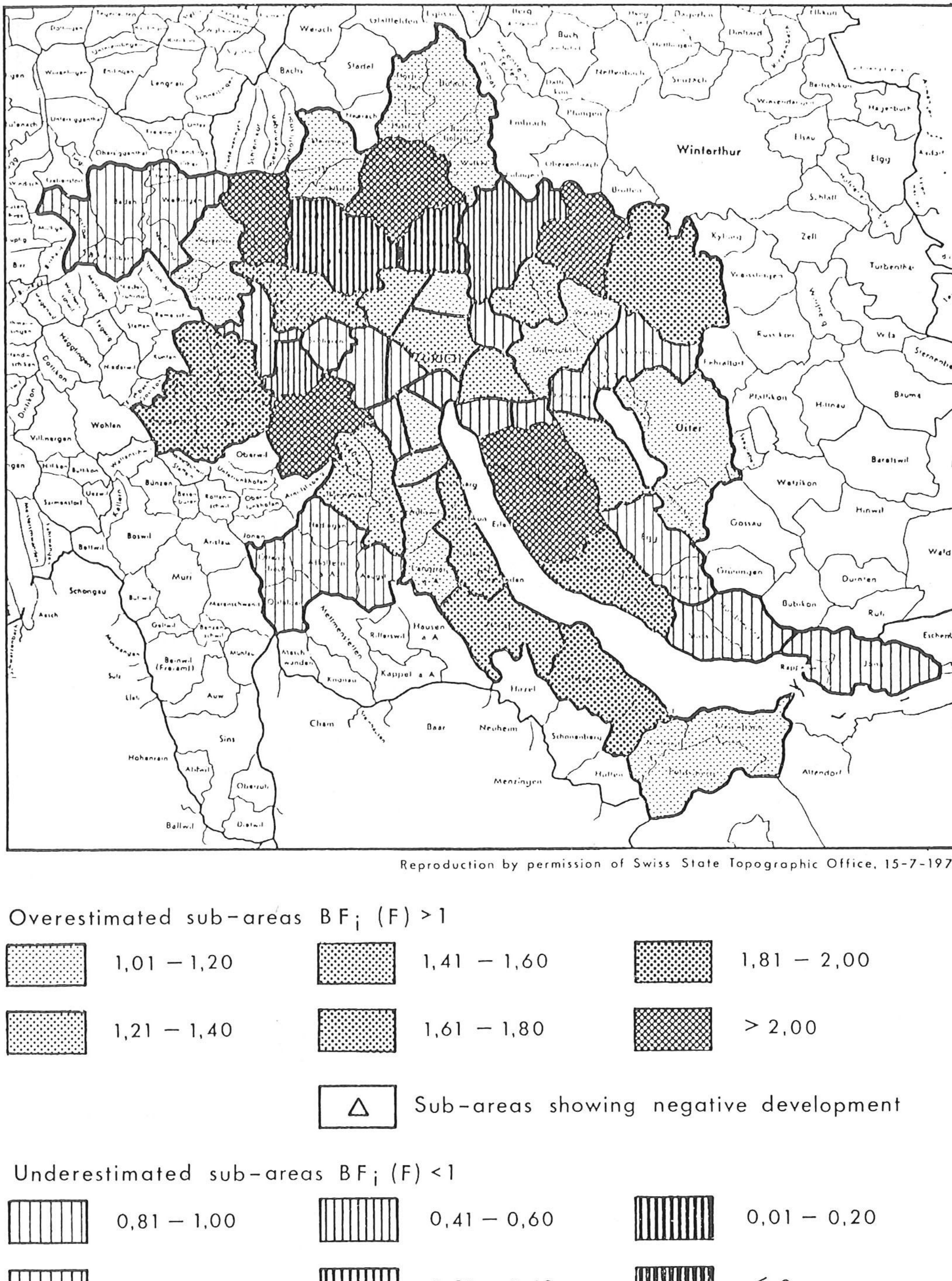
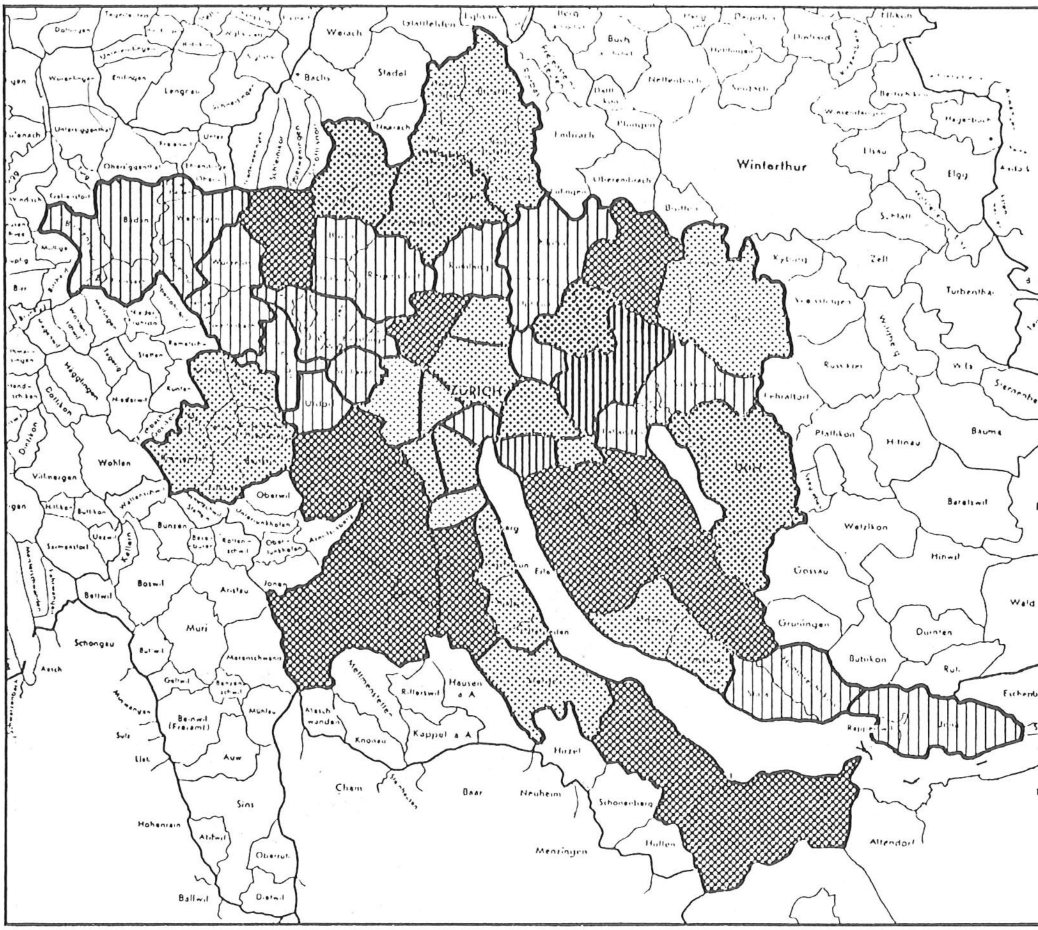


Fig. 22 – Comparison of actual and forecast development of retail land-use at low distance sensibility (Simulation 1a)



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Overestimated sub-areas BF_i (F) > 1

1,01 – 1,20 | 1,41 – 1,60 | 1,81 – 2,00

1,21 – 1,40 | 1,61 – 1,80 | > 2,00

△ Sub-areas showing negative development

Underestimated sub-areas BF_i (F) < 1

0,81 – 1,00 | 0,41 – 0,60 | 0,01 – 0,20

0,61 – 0,80 | 0,21 – 0,40 | ≤ 0

Fig. 23 – Comparison of actual and forecast development of administrative land-use at low distance sensibility (Simulation 1a)

REFERENCES

[1] Abler, R., Adams, J. S., Gould, P., **'Spatial Organization, The Geographer's View of the world,'** Prentice-Hall Inc., New Jersey 1971

[2] Alonso, W., **'Location Theory,'** Regional Development and Planning, A Reader, edited by J. Friedmann and W. Alonso, The MIT-Press, Cambridge 1964, pp. 88 and following.

[3] Anderson, T.R., Egeland, J.A., **'Spatial Aspects of Social Area Analysis,'** American Sociological Review, Vol 26, Number 1, 1961.

[4] Batty, M., **'Dynamic Simulation of an Urban System,'** Geographical Papers No 12, The University of Reading Department of Geography, Whiteknights Park 1971.

[5] Cordey-Hayes, M., **'Dynamic frameworks for spatial models,'** centre for Environmental Studies, CES WP 76, London 1971.

[6] Crecine, J.P., **'A Dynamic Model of Urban Structure,'** Rand Memo P3803, 1968.

[7] Forrester, J. W., **'Urban Dynamics,'** The MIT-Press, Cambridge, Massachusetts, 1969.

[8] Hansen, W. G., **'How Accessibility Shapes Land Use,'** Journal of Am. Inst. of Planners, Vol 25 (1959) No 2.

[9] Ingram, D.R., **'The Concept of Accessibility: A search for an Operational Form,'** Regional Studies, Vol 5, 1971, pp. 101 and following.

[10] Isard, W., **'Methods of Regional Analysis: an Introduction to Regional Science,'** MIT-Press, Cambridge, Massachusetts, 1960.

[11] Kristensson, F., **'People, Firms and Regions, A Structural Economic Analysis,'** The Economic Research Institute at the Stockholm School of Economics, 1967 (unpublished manuscript).

[12] Lachene, R., **'Networks and the Location of Economic Activities,'** Regional Science Association, Papers XIV, 1965, pp. 183 and following.

[13] Leontief, W., **'Die multiregionale Input-Output-Analyse,'** Arbeitsgemeinschaft für Forschung des Landes NRW, Heft 123, Düsseldorf 1962.

[14] Lowry, I. S., **'Model of Metropolis,'** RM-4035-RC, Rand Corporation, Santa Monica 1964.

[15] Richardson, H.W., **'Regional growth theory,** Macmillan Press LTD, London 1973.

[16] Wilson, A. G., **'Notes on some concepts in social physics,'** Centre for Environmental Studies, Working Paper 4, to be published, Papers and Proceedings of Regional Science Association, London 1968.

[17] Wilson, A. G., **'Entropy in urban and regional modelling,'** Centre for Environmental Studies, Working Paper CES WP 26, London 1969.

[18] Wilson, A. A., **'Entropy in urban und regional modelling,'** Pion, London 1970.