URBAN CHANGE, FORESEEN OR IMAGINED?

THE ROLE OF SIMULATION MODELS IN PLANNING URBAN TRANSFORMATION. FORESIGHT FOR WROCŁAW METROPOLITAN AREA

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Cities have been planned for millennia. Planners – whether they were builders, architects, urbanists, surveyors or lawyers – tried to anticipate changes and imagine the future pattern of urban structure. They arranged the civic activities in the agoras and commerce in the market squares. They imagined monumental axes and social housing neighbourhoods. Yet since urban growth has exceeded the level of hundreds of thousand inhabitants the future arrangement, the urban layout, the plan is beyond the imagination of a designer. Planners need more specialised tools to foresee the change and conceptualise the effects of their intervention. Complexity is increasing.

CONCEPTUAL FRAMEWORK OF URBAN STRUCTURE

The conceptual framework of analysing urban structure is still being discussed. One of the important issues determining this debate might be that there is no clear agreement about the meaning of 'urban structure'. This term could be simply understood as a way in which land use of the city is set out, but that does not reflect the complexity of the problem. This meaning mirrors only a stable, fixed picture and only one aspect of the urban structure.

We define urban structure as a mixture of 3 components: (1) an order of the urban elements, (2) the separate sub-systems joining these parts into entire, complex organism and (3) the fabric of the city, its physical form.

This is an easy way to notice than the 'order' is quite abstract – we do not talk about any specific arrangement, we only indicate that there is a setup of urban elements. If there were no flows and relationships between urban elements – this pattern would not play an important role in urban structure. But the fact is that there are flows and relationships between distinct elements and they influence the composition of the city. Indeed, they shape urban structure.

Conversely, what we defined as the 'joining sub-systems' has a clear physical form which allows these flows and relationships to materialise. These are networks of different kinds: transportation, infrastructure, communication.

We need a conceptual framework to describe, analyse and understand urban structure able to explain the way in which it performs and produces spatial effects. Many theories have been used as foundations of such a framework. They are usually rooted in social, economic and environmental sciences. For the last 50 years systems theory and physics have been explored as a source of ideas which can help with comprehensive theory.

One more factor has to be considered: planning practice. All the theories claim to explore urban structure not only to satisfy enquiring minds of a few researchers but also to respond to the need of creating and managing complex urban structures. *'But, if all communities aim at some good, the state or political community, which is the highest of all, and which embraces all the rest, aims at good in a greater degree than any other and at the highest good'* explains Aristotle in the first book of *Politics* (2008). For him 'the state' meant 'the city' as this was the form of the state he knew and studied. Following Aristotle's vision we can assume that urban management aims at public good. While the goal of enterprises is to increase economic profit the goal of the city has to be to increase social profit.

Management means also that effects of spatial processes or interventions have to be foreseen. This is true about management of any type. Management refers to the future. Steering, governance or even only mundane dealing with urban problems require a vision of possible effects of the decisions. This should be based not only on speculations or intuition but also on well defined criteria. In other words, one needs to simulate spatial scenarios for the future. The conceptual procedure reflecting forces which generate urban structure and foresee urban structure has to be defined itself.

> Zipser (1985) discussed one of the most comprehensive theoretical concepts which reflects the essence of urban structure while containing the opportunities of simulating spatial effects. This concept explores the nature of spatial decisions made by people and institutions. It relates to the process of locating numerous inter-connected elements in physical space in relation to the surroundings. This concept was presented as '**PARADIGM OF SPATIAL DECISIONS**'. It consists of 9 constituents:

> **ACTIVITIES** defined as forms of land use and arrangements relevant to the level of development achieved by society;

> **CAPACITY** reflecting 'quantity' or 'volume' of activities which may be implemented in defined area; this is a purely physical feature (areas have a limited size);

> **PREDISPOSITIONS** describing the 'suitability' of an area for a particular activity; there are some spatial/territorial features which are more suitable for specific activities or even required by them (i.e. coal as a natural resource is needed in order to set up a coal mine and a sea or a river is required to set up a port);

> **CONTACTS** representing essential, indispensable relations between activities; this feature is considered as the most important component shaping urban structure;

> **CONFLICTS** revealing mutual, 'interactive' disturbances between activities, which can be considered as 'negative contacts';

> **PREFERENCES** denoting a set of subjective convictions and/or beliefs about space (i.e. that some places are more suitable for a specific activity than others), including professional dogmas and doctrines, as well as political concepts and ideas about 'appropriate' spatial arrangements;

> **BALANCE** articulating the proportion between the number of destinations of contacts (offering supply to demands) and the number of entities interested in this kind of contacts; this feature reflects the general 'stability' of the urban system;

INERTIA signifying inertia and 'disinclination to change' of the existing spatial order and arrangement producing a kind of 'delay' in the implementation of new elements; <

STYLE understood as a cultural scheme of spatial solutions (including 'fashions' in urban design and widely accepted spatial patterns). <

This framework creates a conceptual procedure of examination and description of the urban structure. One of the most important advantages of this concept is 'diagnostic transparency'. Many misunderstandings come from different perceptions of urban structure and variety of evaluation criteria. The paradigm is not a description of a particular urban structure, it is a procedure to study, understand and finally to plan it. This framework is both a source of criteria and a mechanism to place a variety of phenomena into physical space. It is very important to notice, that the paradigm includes both elements of the urban system and their relationships between them. In terms of system's theory this approach describes the (urban) system. The paradigm can be easily used as a framework of theoretical models representing urban structure. <

MODELS IN URBAN STUDIES AND PLANNING

Models represent the reality, they are not reality itself. If the real world is being considered as a system in terms of system's theory – the model represents a system. Different kinds of models can be defined: physical (or 'analogue'), iconographic, conceptual, abstract. Models have been used in urban studies and planning for millennia. Traditionally they were and still are physical or iconographic models (mock-up development, sketches, plans, designs), sometimes they were/are conceptual if we agree that this kind of models uses ideas to represent other ideas (descriptions, manifestos, charters). <

Among widely known conceptual models of urban structure there is the concentric zone model <

described by Burgess in 1925 or the sectoral model examined by Hoyt in 1939. Lynch (1981) defined his models in a different way – as cosmic, practical and organic. More recently, this kind of conceptual models describes polycentric metropolises, city-regions or eco-cities.

- Since the 1960s the focal point has moved towards abstract models describing relations and flows rather than physical form. The typical language of this kind of models is mathematics. The explored relations are often so complex that they require differential and indeterminate equations. Widely discussed models in urban studies were: linear programming, diffusion model, PERT, regression analysis, Lowry-Garin spatial allocation model (Garin, 1966; Lowry, 1964) urban dynamics (Forrester, 1969), cellular automata (Batty, 1997, 2005), gravity model (Voorhees, 1965), intervening opportunities model (Stouffer, 1948).
- Models can represent chosen aspects of the urban system. This characteristic is especially important to understand the nature of the real process. Models very often reduce the analysed elements and relationships in order to follow extracted processes. Simulation models are a specific group of models which allow to 'experiment' on them instead of experimenting on the real system. Simulation models are especially useful when experimenting on the real system is extremely difficult or may produce a serious danger to the system.

THE RANK-SIZE RULE AS REPRESENTATION OF THE FORMULA OF THE URBAN NETWORK AND STRUCTURE. COMPLEX SPATIAL PHENOMENA: CONCENTRATION AND HIERARCHY

- In order to foresee spatial effects of processes of urbanisation one needs to define (or discover) the main driving forces or general rules which influence and control the performance of an urban system. These rules are not models – they simply occur and perform within the urban system. They might be considered as kind of *lex naturalis*.
- One of the most striking regularities of urban network is widely known as rank-size rule. The idea that the size distribution of the cities within a defined area (country, region) can be approximated was articulated in a precise way in 1913 by Auerbach (1913) and then redefined, among others, by Zipf in 1949 (Zipf, 1949).

This regularity has been commented and interpreted for the last half-century and it seems that it hasn't revealed its full spectrum of possible explanations yet.

The construction of the rank-size rule is, from the mathematical point of view, surprisingly simple. Auerbach (1913) suggested that the form of the size distribution of cities takes the Pareto distribution:

$$y = Ax^{-a}$$

where:

x is a particular population size,

y is a number of cities with the population greater than x and

a which is called ***contrast index*** is constant.

Zipf (1949) developed this rule claiming that the distribution of cities could not only follow the Pareto distribution but take a precise value of ***contrast index*** $a=1$.

The final form of Zipf's Law is:

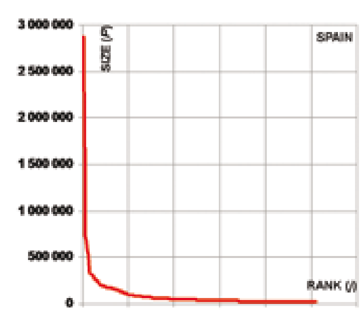
$$P_j = \frac{P_1}{j^{-a}}$$

where:

P_1 is the population of the biggest city within a defined area,

P_j is the population of the city located on the j position within a defined area,

j is the position of the city in the size distribution.

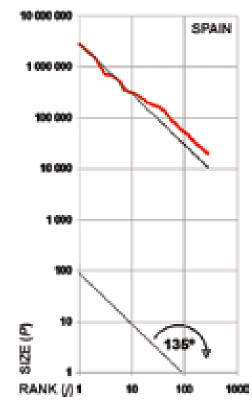


1. Rank size rule of the Spanish cities

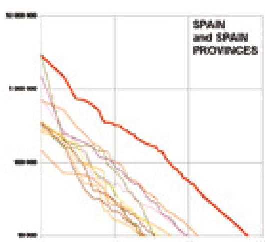
- When one calculates the natural logarithm of the rank and of the city population the resulting graph displays remarkably regular log-linear pattern. Following Zipf's assumption that contrast index $a = 1$, the resulting graph creates the angle of 135 degrees with the horizontal axis (Fig. 2).
- The significant regularity of rank-size distribution applies to the different spatial scales and different times. This is clearly visible on the graph 3a, 3b and 3c presenting rank-size rule relating to region and country: Spain and its provinces (Fig. 3a), continent: Europe and European countries (Fig. 3b) and the world and continents (Fig. 3c).

One of them is **concentration** – as a consequence of the best possible distribution of the activities in the given network of contacts. Concentration is the most 'noticeable' feature of spatial arrangement. Many studies have been conducted concerning concentration – from describing this phenomenon to measuring it (i.e. Clark's and Newling's rule, Gini concetration ratio, Lorenz curve). What is especially fascinating is the mechanism of concentration in real spatial processes. Concentration itself is the result of this mechanism.

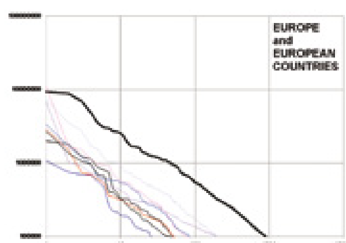
The second is **hierarchy** as an expression of the predilection for the self-organisation of an urban



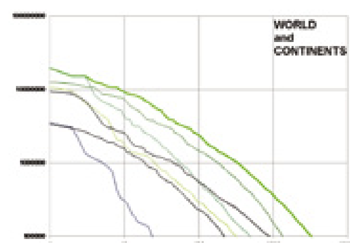
2. Rank-size distribution of the Spanish cities presented in natural logarithm scale



3a. Rank-size distribution of Spain and its provinces in 1998



3b. Rank-size distribution of Europe and the European countries in 2000

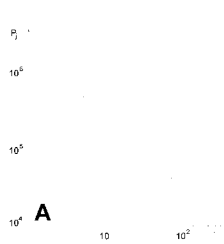


3c. Rank-size distribution of the world and the continents in 2000

- The same regularity can be observed in relation to time. Graph 4 proves that rank-size rule relates to different periods. It displays the distribution of the cities of Poland in 1950, 1960, 1970 and 1975 (a), cities of France in the period of 1831-1982 (b), cities of the USA in the period of 1790-1950 (c) and cities of England and Wales in the period of 1801-1911 (d). The only irregularity of those graphs is the position of the biggest cities of France (Paris) and England (London) which 'overgrew' their countries and relate rather to the continental scale.
- Presented data may mean that there are driving forces able to keep urban networks in accordance with rank-size rule. Nobody can 'plan' this order, nobody even can even influence this regularity easily. This phenomenon reflects the self-organisation ability of the urban system.
- The next significant conclusion of the study of the rank-size rule is that two driving forces can be clearly extracted.

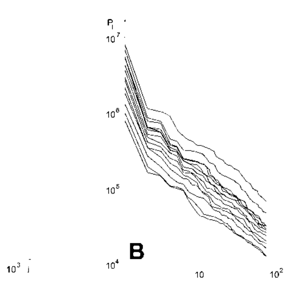
system. Actually we can consider hierarchy as a way of managing concentration. Quite evident is that urban systems are not 'flat', quite the reverse, there is a strong tendency to structure the network. Hierarchy is one, but probably the most efficient, of the possible patterns of this structure. It is likely that rank-size rule expresses a very important driving force shaping urban structure.

In this paper we consider concentration as a result of contacts shaping urban structure. Using the paradigm of spatial decision as a theoretical framework of urban structure and the rank-size rule as an expression of the rules of urban processes we will focus on opportunities of modelling spatial scenarios for the future by using simulation models. Concentration as a result of contacts can be simulated by using mathematical models of this process. In this paper we will use the intervening opportunities model and explore the possible



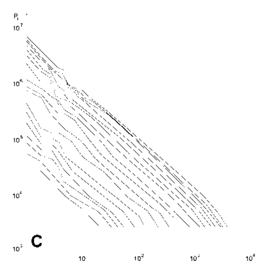
4a. Rank-size distribution in Poland 1950, 1960, 1970 and 1975

source:
Zagożdżon, 1979



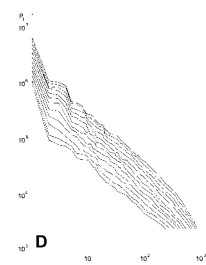
4b. Rank-size distribution in France 1831-1982

source:
Guerin-Pace, 1990, Haag and Max, 1995



4c. Rank-size distribution in the USA 1790-1950

source: Robson 1973;
Zipser and Mlek, 2005



4d. Rank-size distribution in England and Wales 1801-1911

source: Robson 1973;
Zipser and Mlek, 2005

application of this tool in order to foresee spatial effects of urban intervention. We will deliver an interpretation of the results.

ALLOCATION MODEL BASED ON THE MECHANISM OF INTERVENING OPPORTUNITIES

CONCEPT OF INTERVENING OPPORTUNITIES

> There are two groups of models representing the configuration of contacts in urban structure. Assuming for urban research that contacts are mostly responsible for shaping urban structure this kind of models plays a fundamental role in defining rules and mechanisms of relationships producing spatial effects. The first group is based on the gravity model whereas the second group is based on the less used intervening opportunities model.

> The basic concept of the intervening opportunities model formulated by Stouffer (1948) is that the trip distribution is not directly related to distance but rather to accessibility of opportunities. Assuming that people travel in order to satisfy their needs, Stouffer analysed the behaviour of an individual choosing possible destinations for a particular trip. Stouffer theorised that the migration between origin and destination places depends not only on number of opportunities given by the latter but also on the amount of intervening opportunities between these two analysed places. Stouffer's assumption was that these intervening opportunities form a set of occasions competing with the final destination which is located farther. In other words they may stop the trips from going to the final destination by offering them opportunities to satisfy their need (trip finishes when the particular need is satisfied). The distance in Stouffer's concept is expressed in the number of opportunities not in typical units of measurement like kilometres or miles. However, the occasions are arranged in the order of increasing distance.

> Schneider (1959) proposed a modification of Stouffer's initial concept using probability as descriptive tool. The mathematical tool requires assumptions concerning the spatial decision making process. The structure of this process describing 'average' human behaviour in this regard is as follows.

In order to supply his/her needs an individual tries to involve the lowest possible effort. This is why he/she looks for opportunities starting from the place where he/she is located (this can be the place of accommodation, business, school, etc.). The nearest occasion can be rejected if it does not meet defined criteria. Given the variety of motivations it is likely that the first occasion cannot fulfil the expectations of the travelling individual. In the case of rejection he/she has to continue his/her travel. The trip terminates when the opportunity is accepted. Of course the general model cannot follow each individual motivation and has to construct statistical profiles of the 'travellers'. The trip is represented by the draw which may end with acceptance or rejection of the occasion. Consequently, the decision-making process is represented by a random variable which can have two possible values: success or failure (accepted or rejected occasion). <

In other words the process of executing the contact in Schneider's concept is represented by the series of draws (CATS, 1960). Each draw can finish with failure (occasion has not been accepted, trip continues) or success (occasion has been accepted, trip terminates). In mathematical terms this is a Bernoulli distribution. Schneider's hypothesis states that the probability that a trip will terminate in some volume of destination points is equal to the probability that this volume contains an acceptable destination multiplied by the probability that an acceptable destination closer to the origin of the trips has not been found. <

This can be expressed as: <

$$P\{N = n\} = pq^{n-1}$$

where

n – length of the series consists of $n–1$ failures preceding the first success,

p – probability of success in the Bernoulli distribution,

q – probability of failure in the Bernoulli distribution.

> Having defined the probability the expected value of the random variable can be calculated:

$$E(n) = \frac{1}{p}$$

> This value in mathematical terms expresses the average number of failures preceding the first success. This is to say that this value describes an average length of the trip (measured in occasions not in kilometres).

> The consequence of this equation is that if the average length of the trip is known the probability of the success (*p*) can be calculated. This is a very important remark because it permits to obtain the value of *selectivity* – the only parameter of the intervening opportunities model.

> In practice two more simplifications have to be made. First, in mathematical terms we have to switch from the discrete distribution to continuous distribution. Considering each separate occasion within a big urban structure could be very difficult or even impossible. This is why it is quite reasonable to aggregate both the starting points (origins) and the opportunities (destinations) from the defied areas into nodes representing them. These areas have to be precisely defined to represent the reality. For example each point within an area has to be accessible in 5 minutes which seems to be a proper approximation in the city of 500.000 population. This is the second simplification. Furthermore, the destination nodes can be arranged into zones which are accessible using more or less the same effort (measured i.e. in distance, time, money) from the origin. This simplification is acceptable when one calculates hundreds of thousands or sometimes millions of occasions.

> As a consequence the probability that the trip which has started in the origin node *i* will terminate in the zone *j* which contains a_{ij} occasions is given by:

$$P_{ij} = e^{-sc_{ij}} - e^{-s(c_{ij} + a_{ij})}$$

where:

c_{ij} is the number of occasions between origin point *i* and destination zone *j*,

s is the selectivity.

Hence, the trip distribution T_{ij} between the origin node *i* containing O_i travellers and the zone *j* equals: <

$$T_{ij} = O_i[e^{-sc_{ij}} - e^{-s(c_{ij} + a_{ij})}]$$

If zone *j* contains more than one destination node the final distribution between nodes located in the zone *j* has to be calculated: <

$$T_{ij} = O_i[e^{-sc_{ik}} - e^{-s(c_{ij} + a_{ik})}]\frac{D_j}{a_{ik}}$$

where:

a_{ik} is the number of opportunities in zone *k*, which contains the node *j* (or in the mathematical terms $a_{ik} = \Sigma_n D_n$ for *n* within zone *k*),

c_{ik} is the number of opportunities between origin node *i* and zone *k* (or $c_{ik} = \Sigma_{m=1}^{k-1} a_{im}$),

D_j is the number of opportunities in the destination node *j*,

s is the selectivity.

The only parameter of the intervening opportunities model is the *selectivity*. This parameter expresses a feature of 'being finicky'. In other words selectivity represents inclination to accept substitute. Of course this inclination relates to need. The more complex or sophisticated need is the less likely it is to be replaced with a substitute. For example, the process of choosing milk or croissants for breakfast is quite simple. If our favourite croissants are not in the nearest bakery we can go to the next shop but it is not likely that we would go to the city centre trying to get the 'best ever' croissants for breakfast on Wednesday. The selectivity will be 'soft'. <

When the need is more complicated the process of choice is more complex. If for example we wish to buy a new motorbike it is not likely that we would accept the nearest occasion. If we have dreamt about Ducati Monster M696+ in black colour it wouldn't be possible to accept for instance Yamaha YBR125 or even BMW G450 X only because the Yamaha or BMW dealer are located closer to our home. These bikes are produced for a different 'market target' and for a different purpose. Maybe we could consider red or blue instead of black or consider other motorbikes in a similar class like for instance Yamaha Fazer8 or Honda CBF600, but <

definitely the distance from the dealer wouldn't play any role in the process of selection. In this case selectivity will be very 'sharp'. The same may be said about the selection of the university or the holiday place. The selectivity rises when the good is of high rank. These examples clearly show that selectivity relates to lifestyle and level of civilisation of a given society.

ALLOCATION MODELS: ALLOCATION OF THE DESTINATIONS MODEL

> Using Stouffer's and Schneider's concepts as a base Zipser (1972) developed a theoretical and formal simulation model emphasising the process of generating concentration as a main driving force shaping urban structure. Intervening opportunities mechanism reflecting the contacts within this structure seemed to be an ideal tool in this respect.

> Allocation models based on mechanisms of intervening opportunities (Zipser, 1972) mirror the process of shaping patterns of concentration by relocating origin and destination activities looking for a balance (or more widely – equilibrium) in urban arrangement. The given, stable element in these models is accessibility – in practice the transportation network – while varying the chances of different urban elements to be explored as destinations. This determinates the entire urban structure.

> It is essential to remember that allocation models reflect only one particular aspect which shapes urban structure – contacts which are additionally limited to the kind of extracted contact (i.e. home-work, home-leisure, work-services, etc.).

> Many kinds of allocation models have been defined. One of them is '*allocation of the destinations*', model which is very useful in studying tendencies of concentration. At the beginning of the simulation process urban structure is defined by the nodes representing origin and destination activities. Origin nodes are 'starting points' of travel aiming at satisfying particular needs in destination nodes. The value of the nodes depends on the kind of contact. For example origin value in contact home-work are residents wishing to work (in practice all adults) and destination value are workplaces. They travel using defined transportation networks (different kinds of networks can be used – roads, rails, public transport, etc.). The basic assumption is that a good measure of attractiveness of the place is how many people look for satisfaction of their need in the particular place. This is why the process of simulation is based on allocation of destinations from the nodes where they haven't been accepted to the nodes where surplus of arrivals has been noticed. This surplus in reality means unsatisfied need.

As the 'allocation of destinations' model ensures freedom of choice in accepting the occasion, the next step in the process of simulating urban structure is to move destination activities from the nodes in which there is shortage of arrivals (acceptance) to those where a surplus of arrivals has been registered. This procedure is repeated until the entire system achieves a balance. This is to say – until the number of arrivals to each particular node equals the number of destination activities in this node. <

The big advantage of this model is that one can use 'imagined' data in order to test the reaction of the system. For example simple population volume can be used as origin value to verify trends of concentration, while destination value can be different from reality (i.e. destination value can reflect planned, future state). Different networks (including those not yet existing) can be used as a base of circulation. Thus 'allocation of destinations' model can be used to study spatial effects of development (both planned and unplanned). <

Summing up, the representation of the 'real world' in the 'allocation of destinations' model is as follows: <

- nodes represent urbanised space,
- the transportation network defines accessibility of the nodes,
- origin and destination values are located in the nodes,
- the selectivity parameter expresses adequate value for contact profile.

> The result of the simulation process does not reflect 'the possible future' – it reflects trends and tendencies. Analysing procedure of simulation one has to understand that

- when using simulation models of urbanised space and models reflecting the concentration process – they reflect only chosen aspects of reality, they are not reality itself;
- only one of the 9 elements of the paradigm of spatial decision making is being taken into account at the time.

> The model does not give 'direct' answers; the results should be studied and interpreted.

SIMULATION DATA AND PROCESS OF MODELLING

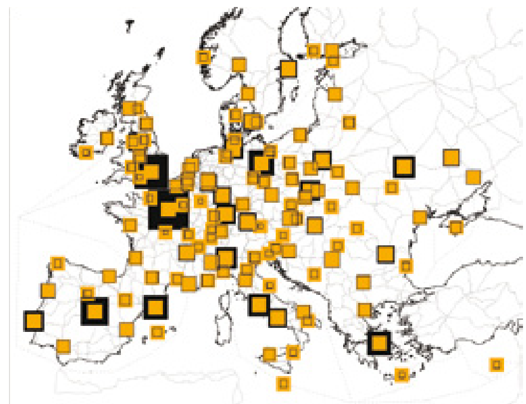
> One of the best possible ways of verifying the usefulness of the simulation models is to test whether they are able to reflect reality. This is to say that one can assume that the model represents the real world precisely if the model can produce the existing state of an analysed aspect of reality. This depends also on data used in the process of simulation.

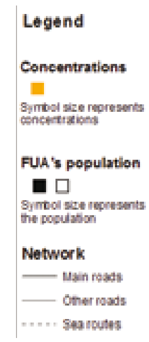
> The big advantage of the 'allocation of destination' model is that we can use quite simple statistical data and descriptions of the transportation network.

> This procedure will be illustrated with the case of the simulation of the European urban structure. Our aim was to follow trends of concentration in Europe. Source data were 123 nodes representing FUAs – Functional Urban Areas defined in the ESPON Atlas (ESPON, 2006, pp. 29) supplemented with a few chosen cities from Eastern Europe. The Functional Urban Areas consist of wide territories, but in the process of simulation they are represented by nodes located at the junctions of the transportation network. The form of the network and its parameters, especially the average speed value in each particular segment, defines the accessibility of the nodes (Fig. 5).

5. *Simulation of the European urban structure – source data: nodes and transportation network*

Origin values match the population of each node (ESPON 2005, pp. 257-291). The sum of origins equals the volume of destinations. Destinations are equally distributed, which means that each node has the same value (Fig. 6). <

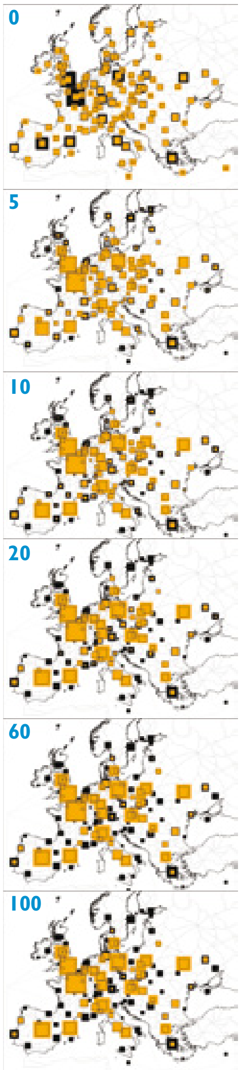




6. *Simulation of the European urban structure – source data: origin and destination values*

According to the formula of the 'allocation of destination model' the first step is to send origins (people travelling in order to satisfy their needs) and observe which nodes have been accepted and which nodes have experienced shortage of acceptance. This result is the starting point of the next iteration. In other words after calculating the complete exchange of contacts in the system during the first iteration we allocate destinations. The value of destination in each node has to be recalculated and is not equally distributed anymore. This kind of simulation might be compared with the real process of locating services. Companies look for the best place to attract clients. They follow client's choices in order to increase the number of customers. <

Our simulation has a speculative aim. We didn't assume any particular need but we wanted to test whereas in a given transportation network the European urban structure is driven by a concentration force the way it is described in an intervening opportunities model. The process of simulation is repeated until only a very small number of destinations has to be allocated (i.e. 2%). This means that the system has achieved the <



7. Simulation of the European urban structure – initial arrangement and results after 5^{th}, 10^{th}, 20^{th}, 60^{th} and 100^{th} iterations.

state of equilibrium. We performed 100 iterations analysing the process of simulation of European urban structure. The result of a few chosen iterations is displayed on the Fig. 7.

Analysing the results one can observe two significant phenomena. First, that the model reflects the power of concentration very well, and secondly – the essential influence of this driving force in the urban structure. After 5 iterations the accordance with the reality is already quite great. Only peripheral nodes (cities) are underprivileged which is a typical characteristic of the model. This is to say – the accessibility to the peripheral nodes is worse than that of more central locations. If we perform more iterations the nodes with better accessibility will 'pick up' the population like a suction pump. This explains in what way the model reflects concentration as a driving force. The final result doesn't reflect 'reality', it mirrors the tendency and describes the driving force.

APPLICATIONS OF THE MODEL

The simulation method is successfully applied for the analysis of settlement systems varying in scale and complexity. The mode and precision of representing such structures depend on the purpose of the simulation. This means that what question is being considered is very important. Fig. 8 presents the application of the model to the continental, regional and metropolitan scales. It can be clearly noticed that concentration as driving force influences every scale of urban structure and produces a specific pattern of hierarchy in a given accessibility. Knowing the way the model performs one can judge and study the attractiveness of particular places.

THE IMPACT OF DIFFERENT NETWORKS

Accessibility is not easy to be imagined. Relaying on intuition in this respect may lead to huge mistakes within complex urban structures. This is why models representing contacts are so useful. The system of accessibility that depends on the shape of the transportation network and the speed of particular segments of this network influence strongly the result of the simulation. It happens that very little change of the network (i.e. adding a new segment or improving parameters of an existing one) changes the results totally because it re-defines accessibility. On the contrary in other cases declared 'improvements' of the transportation network do not influence the simulation results at all.

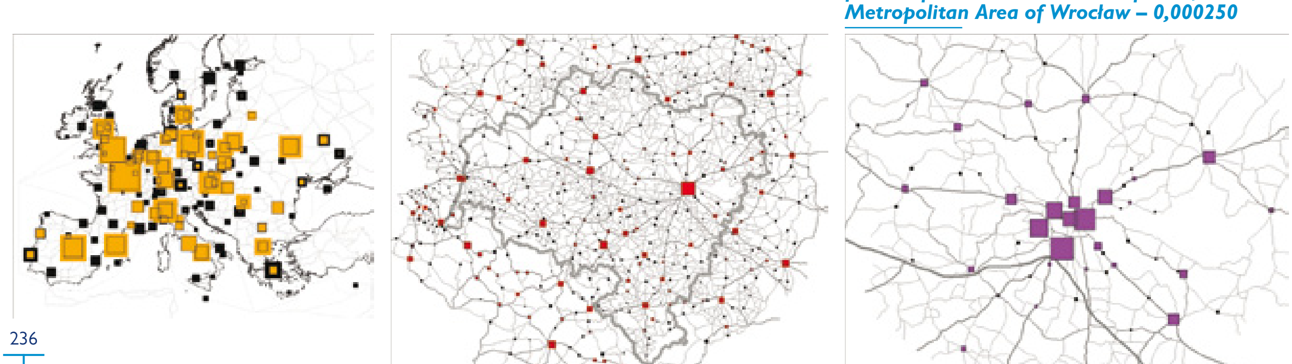
The Metropolitan Area of Wrocław illustrates this kind of 'reaction of the system' (Fig. 9). We can observe only a slight influence of the planned network on the results of simulation after 100 iterations of modelling, however, all other parameters remain unchanged. We will explore this modelling in the following section.

THE IMPACT OF DIFFERENT CONTACT TYPES – CHANGES OF SELECTIVITY PARAMETER

Observing the simulation of the Metropolitan Area of Wrocław we can notice that the influence of a selectivity parameter on simulation results is significant, when comparing two extreme values of a selectivity parameter (Fig. 10). Higher selectivity value ('soft') corresponds to the situation when travellers are satisfied with destinations which are quite close to them in the space of opportunities. Lower selectivity value ('sharp') means that many of subsequently encountered destinations are omitted by travellers before they finds the destination of their trip. This expresses also the importance of the need, whereby 'sharp' selectivity is typical of higher rank needs.

Higher selectivity value in the simulation process will result in many small concentrations of destinations. We can interpret them as locally attractive places. Lower selectivity value is favourable to achieving one or a few high concentrations of destinations. Their locations are attractive in a wider (i.e. regional) scale for travellers who are prepared for a longer trip.

8. Application of the 'allocation of the destinations' model to diverse scales of urban structures – results after 100 iterations for Europe, the Lower Silesia region (W-S Poland) and the Metropolitan Area of Wrocław. The origin value reflects the real population and the destinations were initially equally distributed; selectivity for Europe and Lower Silesia equals 0,000025 and for the Metropolitan Area of Wrocław – 0,000250



9. Application of the model to examine the impact of different networks on the Metropolitan Area of Wrocław: results after 100 iterations of modelling conducted respectively on the real and the planned network from initial real origins and an even distribution of destinations; selectivity equals 0,000250, 0,000050 and 0,000005 ('sharp')

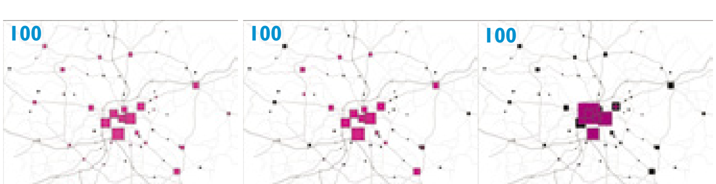
DEVELOPMENT SCENARIOS FOR THE METROPOLITAN AREA OF WROCŁAW. SIMULATION RESEARCH.

The simulation was conducted for the Metropolitan Area of Wrocław (MAW) that covers the city of Wrocław and the towns located within a distance of 35 km from Wrocław. Borders of the MAW are almost the same as the administratively delimitated metropolitan area; the only exception are southern and northern peripheries of the area which were not taken into consideration. We applied the model 'allocation of the destinations'.

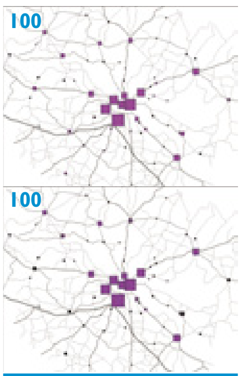
The research was aimed to compare various simulation results. We conducted the simulations that used the existing and the planned transportation networks, as well as different selectivity parameter values that represented the variety of contacts. Therefore the simulation results which used different selectivity values were considered equally. They reflected preferences of various users of the urbanised structure. Special care was taken of the stability of the structure. As it can be noticed the results of simulations are similar using different parameters. Since the change of the network type does not influence the properties of the MAW structure significantly, the next set of modelling was based on the modification of origin values. In order to obtain more accurate results the analysis was conducted on a more detailed representation of the settlement structure of the MAW. The modelling results are described below.

SIMULATION OF THE EXISTING STRUCTURE

The model of the existing structure of the MAW consists of 62 nodes. 9 represent different parts of Wrocław, 13 are located in the surrounding towns and the other 40 nodes are the villages over 1.000 inhabitants. The origin values located in the nodes are the same as the real population in the administrative units and villages in 2004 according to statistical data. The sum of origin values is the same as the sum of destination values (922.513). Destination values are distributed evenly, which means that each node contains an average value of



10. The impact on simulation results of different contact types represented by changes of selectivity parameter. Case study of the Metropolitan Area of Wrocław – results after 100 iterations of the simulation conducted on the planned transportation network from initial real origins' and even destinations' distribution; the selectivity equals respectively 0,000250 ('soft'), 0,000050 and 0,000005 ('sharp').



11. Modelling of the existing MAW structure – results after 100 iterations of simulation conducted on the existing network and two different values of the selectivity parameter (0,000250 and 0,000050); destination values in colour with origin values in the background

origins falling on every node (14.879). The existing transportation links between nodes were used as a representation of accessibility. The segments of the network are described by speed ranging from 30 to 90 km/h. These values represent the realistic average speed on road segments being considered. The location of the A4 motorway junctions is especially important because they allow access to the fastest transportation route. The modelling results are presented on the Fig. 11.

The result clearly displays the dominant position of the city of Wrocław which is, however, divided into nine nodes. In the surroundings of Wrocław only the nodes located very closely to the city in the South and the East have the ability to attract higher destination values. In the North-West zone between Wrocław and the 'ring' of smaller towns there is an 'infertile crescent' that represents the area of very low attractiveness, where only very few and weak concentrations can be found.

An interesting regularity has been noticed concerning 'ring towns' of Wrocław. Towns located north to Wrocław and one southern town (Oława) attract destinations in a good proportion the their real size whereas towns located south to Wrocław (Kąty Wrocławskie, Gniechowice, Kobierzyce, Żurawina, Środa Śląska, Jelcz-Laskowice) seem to be too close to Wrocław to compete with it. They easily lose destination values to the nodes located in Wrocław, however they can be quite attractive for contacts occurring at the local scale.

SIMULATIONS OF PLANNED URBAN STRUCTURE

The essential difference between simulations of existing and planned structure was accessibility. This is to say that the transportation network used in the latter was adopted from the local and regional plans. This means that the real transportation network was supplemented by the connections not existing yet but already accepted as future solutions. The most significant changes were three bypasses: internal for the city of Wrocław (the downtown bypass), motorway bypass and metropolitan ring road connecting towns around the city. The model representation of the urban structure (nodes, origin and destination values, selectivity) remained the same as in the first set of simulations.

We addressed the issue in what way the new transportation network would influence the structure of the Metropolitan Area of Wrocław. We would like to explore the problem if the system itself would generate new 'magnets' only by increasing accessibility. This question was especially interesting in the context of the planned 'West Pole' which is expected to create the new, specialised 'centre' of the city (see Ossowicz in this book, pp. 25). The modelling results are presented on the Fig. 12.

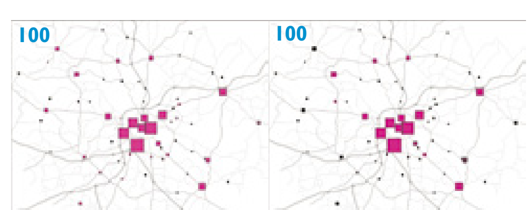
The most remarkable – and in fact rather unexpected! – result of this set of simulation was that almost nothing had changed. Massive investments in infrastructure didn't result in new points of concentration. Four main phenomena might help explain this surprising result:

- the express bypass has sparsely located junctions, thus has only little influence over travel at the local level; moreover they duplicate the main radial of an already existing transportation network,
- the metropolitan ring road connecting the towns around Wrocław doesn't reflect the connections between these places and the main city, which are stronger than the relations between the towns themselves, so that its existence has little influence on new points of concentration,
- a few new connections are only of local importance (Wrocław Old Town ring road or eastern metropolitan road), and
- the model is not very detailed so that it cannot reflect properly the increase of attractiveness at the more local level.

This last assumption was the reason we decided to conduct a more detailed simulation presented in the following section.

The differences between the results of the simulation of existing and planned structures

12. Modelling of the future MAW structure – results after 100 iterations of simulation conducted on the planned network and two different values of the selectivity parameter (0,000250 and 0,000050); destination values in colour with origin values in the background



of the Metropolitan Area of Wrocław were not very significant, albeit some of them are worth considering. The metropolitan ring road connecting the towns located around Wrocław improves the growth conditions of these towns slightly compared with the previous set of simulations. This is especially true about towns located on the motorway junctions. The metropolitan ring road results in significant growth of Brzeg Dolny – the town located to the North West of Wrocław which attracts almost all the destinations from the surroundings (i.e leaving the town of Wołów located on the outskirts of the analysed system without any destination). Application of 'soft' selectivity which favours local concentrations produces a first hint of concentration to the west of Wrocław (the town of Miękinia located near the motorway junction).

SIMULATIONS OF IMAGINARY STRUCTURES

> Models – as it has been already explained – are especially useful while experimenting on them instead of experimenting on the real system. We were playing this kind of game when trying to figure out what should be done to shift the existing urban structure to a new level of arrangement.

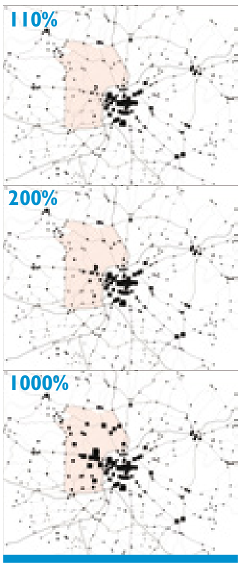
> Simulation was conducted on a more detailed representation of the MAW structure. This time 505 nodes were located in each junction of the planned network. These nodes reflected the urban structure in a more precise way and enabled us to recognise attractiveness of the places on quite a local level. Origin and destination values were estimated on the basis of data used in previous simulations (2004). While estimating origin values real population was distributed evenly among nodes according to their administrative location. This distribution completed the arrangement of 40 villages of over 1.000 inhabitants.

> The research aimed to evaluate the ability to reshape the MAW structure due to changes of the distribution of origin values. This reflected the potential of the places. This is to say that we tried to estimate how big investments had to be made before the system would achieve the ability of 'magnets' generating new urban concentration. Special attention was paid to investigating changes which follow the strengthening of the surroundings of the planned West Pole of Wrocław. In two previously conducted sets of simulations nodes located in this area did not concentrate destination values, in contrast to the nodes located to the East of the city.

The 'Western Zone' was established and located among the motorway bypass of Wrocław, route No. 5 to Poznań, the metropolitan ring road and the A4 motorway running on the southern outskirts of the city. Origin values in the Western Zone were enlarged only for the nodes located inside the zone and those in the city of Wrocław. Junctions located on the border of the Western Zone and nodes located in the administrative units of Oborniki Śląskie, Brzeg Dolny, Środa Śląska and Kąty Wrocławskie were disregarded. We tested three different levels of enlargement of origin values. First, the existing values were increased by 10%. Having statistical data analysed (Tab. 13) we discovered that during the period 2004-2009 the average increase in the Wrocław Poviat (county) had a similar value (11,16%). This value was the biggest growth recorded in all poviats at that time. Even more interestingly, the growth was observed only in the Wrocław subregion and the poviats located close to Wrocław Poviat. We assumed that the 10% increase was a reliable description of natural social processes. For the simulation experiment this growth was concentrated in nodes of the Western Zone.

TERRITORIAL UNIT	CHANGE 2004-2009	
	[%], 2004=100%	[RESIDENTS]
Lower Silesia Voivodeship (region)	0,994	-16428
Wałbrzych subregion	0,976	-16371
Jelenia Góra subregion	0,983	-10002
City of Wrocław subregion	0,993	-4122
Legnica and Głogów subregion	0,995	-2014
Wrocław subregion	1,030	16081
Strzelin Poviat	0,988	-536
Wołów Poviat	0,994	-272
Milicz Poviat	1,004	145
Oleśnica Poviat	1,008	816

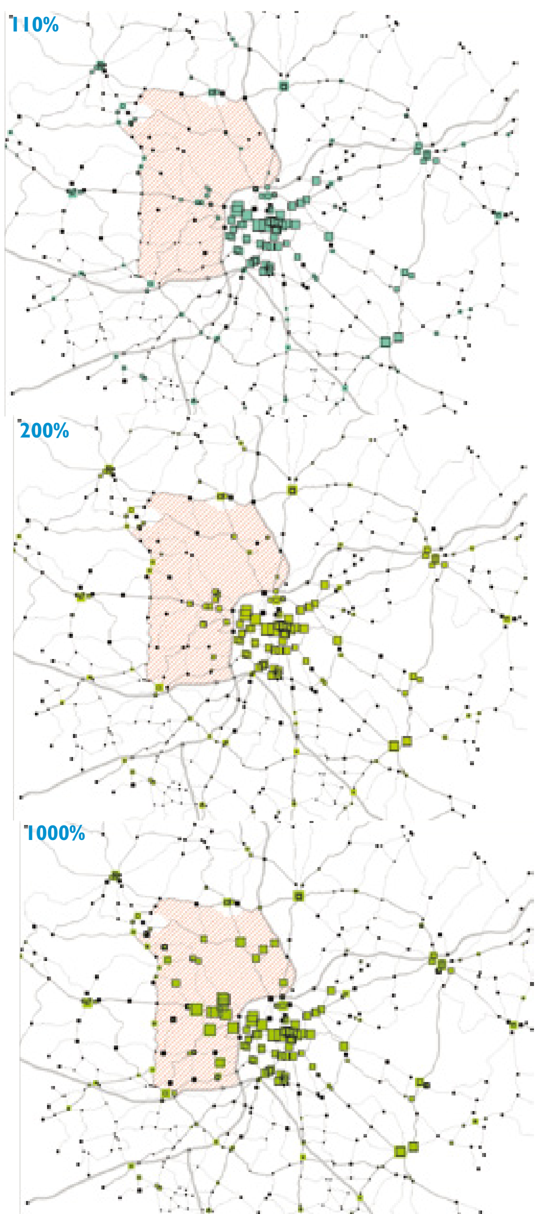
13. Population changes in selected Lower Silesia territorial units (period 2004-2009)



14. Distribution of origin values in the simulation of the West Zone – implementation of 10%, double and tenfold population increase in the Western Zone node values

In the second simulation the origin values were doubled and in the third – we performed with 1000% growth. (Fig. 14).

Simulations were undertaken using only one selectivity parameter value. This was the biggest value applied in the two previous sets of simulations (0,000250). The selectivity we used was 'soft' in order to favour the short trips rather than the longer ones. The exact value of selectivity varied slightly because in each simulation the sum of enlarging origin and destination values was different. The results of the simulations are presented on the Fig. 15.



15. Results of 100 iterations of West Zone modelling – final distribution of destination values achieved with 10%, double and tenfold increase in the Western Zone node values

General results confirmed the strong position of 'ring towns' around the city of Wrocław. Only few new concentrations can be noticed at junctions of the metropolitan ring road (especially notable west to Wrocław, near Mięknia), which proves the stable position of the structure of Wrocław and its 'satelites'.

Enlarged potential of the West Zone does not significantly affect the South-East zone of the surroundings of Wrocław which retains its attractiveness. The only difference is the local rearrangement of the concentrations. Finally, increased values of the nodes located in the Western Zone do not noticeably transform existing arrangement, but they complete it with some new local concentrations.

The Western Zone was our urban laboratory of transformation. What have we learnt from the lesson? First, potential of the place would have to be enlarged enormously to show visible concentrations although they are expected by local planners. Yet, even in the case of enormous increases, the existing concentrations (i.e in and around 'the town within the city' – Leśnica) are stronger and able to attract more destinations than newly created nodes. Secondly, the area located on the northern bank of the Odra river is 'cut off' from the benefits of growth. We notice very few concentrations in this area and in order to 'get started' they require enormous increase of their potentials. Thirdly, the southern part of the Western Zone has quite a low capacity, with the exception of one node (Somlec-Pietrzykowice), to attract destination values.

Analysing the results we must remember that we use a model of reality with all its limitations. This model is enriched with imaginary enlarged values of potentials of the Western Zone. Population enlargement of this kind in the real world would require new investments like roads, infrastructure, commercial, services, etc. These changes would probably affect the position of a few nodes by changing the position of some nodes and bridges. We have to remember that this is only a 'scenario game' displaying trends and tendencies, not 'possible future'.

> The research clearly displays very important characteristics of the urban structure:
- the existing arrangement is very stable and it is not easy to shift it to a new level of organisation,
- improvements of accessibility play an important but not ultimately a decisive role in increasing the attractiveness of places,
- in order to 'switch' the urban system onto a new track of self-organisation massive investments are required.

CONCLUSIONS

> The metropolitan system of Wrocław is dominated by the city, because of geographic and historic conditions. Wrocław is located in the most convenient place to cross the Odra river, thus the regional transportation system is centre oriented and converges in the city. The radial transportation network strengthens the system of 'dependence' between Wrocław and its 'ring towns'. This structure is very stable, and the planned metropolitan ring road connecting 'ring towns' does not change the general relations between them and Wrocław. The metropolitan ring road is very important for the ring towns at a local scale. Implementation of this connection into the regional transportation network would be an effective stimulus for the development of the ring towns and settlements at other ring road junctions.

> The simulation mechanism emphasises the impact of concentration forces on urban structures. Therefore it is not easy to achieve concentrations located in the surroundings of Wrocław. However simulation results helped us to observe the noticeable attractiveness of nodes in the South-Eastern zone, which is caused by existing investment density and network structure with the planned poviat ring road as an enhancement. The attractiveness of the South-Eastern zone and the lack of concentrations in the West Zone are the structural characteristics of Wrocław's vicinity. In the Western Zone the transportation network and urban structures are dispersed and only Leśnica attracts sufficient contacts to achieve the position of a local centre. Simulation attempts to achieve new concentrations in the Western Zone, based on enlarging node values, were only effective if they are dramatically changed. However, such an increase of population in the real space would have a serious impact on investment density.

The tool we presented to support urban planning should be applied with awareness of all its limitations and simplifications. Although not being perfect, nevertheless it assist in obtaining a deeper insight into processes which are not clearly observed or imagined. We cannot interpret the simulation results as a straight answer because we use a model of urbanised space and a model of the concentration process. By observing simulation results we can estimate general characteristics of an urban system. The model we use is a concentration model and does not encompass other factors of the paradigm of spatial decisions. The simulation results of more complex and sophisticated models (i.e. the ORION model which encompasses all elements of the paradigm) have yet to be interpreted. Simulation conducted on the Metropolitan Area of Wrocław revealed stability of existing node attractiveness resulting from the radial network structure and domination of Wrocław. Although the modelling results have to be interpreted, simulation methods are a useful and effective way to examine urbanised structures. <

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