SYSTEMS CONCEPT AND URBAN DEVELOPMENT MODELS

By

T. MEGGYESI and E. VAJDOVICH-VISY

Department of Town Planning, Technical University Budapest

(Received September 25, 1972)

Presented by Prof. Dr. I. PERÉNYI

1. The Systems Concept

In the approach to complex problems like urban development it is useful to consider their components as interrelating parts of a system, rather than treating each component separately. In the last two decades, scientific investigation methods of this nature have been developed, making use of the techniques of structuralism, operations research, cybernetics and information theory. The underlying theory of these methods is what is called the *systems concept*. According to this concept, every phenomenon of the world can be viewed as an entity composed of interrelating parts. The specification of a particular system is largely a pragmatic matter: its boundaries are established in the way that is useful for the purpose of enquiry. The structure of the system is formed by the set of its elements and their relationships. Furthermore, every system has an environment, that is, the relations of the system to other systems have to be accounted for, in order to avoid mistakes arising from the arbitrary delimitation. The relation of the system to its environment depends on the degree of its relative isolation (in other words, on the level of communications), as well as on its capacity to develop behavioural patterns in order to react to different stimuli, and to change its own structure if required.

The system has a hierarchical structure, that is, it can be broken down to less complex subsystems until the lowest-level subsystems can be dealt with in their entirety. The relations among subsystems can be described as flows of energy, information, material or people. In order to maintain its structure, i.e. to keep its balance in the ever-changing conditions created by its environment, the system has to respond to the external stimuli, and react to the changes of the environment. This is what is called the systems behaviour.

The above described conceptual features of the systems make it possible to establish an analogue between one system and another, and thereby deduce some properties of the less familiar system by analogy with the more familiar one.

The systems concept can be applied in two areas of urbanism: first, in scientific enquiry aiming at the understanding of the spatial structure of cities and regions and the main tendencies of their evolution (the same applies to education), and second, in the planned control of development, a practice based on the former but — owing to its operative character — raising further requirements. The view of an urban area as a system involves the modelling of this system: an abstract representation of reality with the purpose of interpreting some of its properties.

2. Mathematical Modelling of Spatial Systems

The notion of mathematical modelling — as shown by the denomination — involves also the simulation of some phenomenon on a model. An arbitrarily delineated part of the real world is considered as a system, and its quantifiable elements are interpreted as functions of one another. In a mathematical model, the interactions of, and flows among the elements are expressed as algorithms. These relations are described either as analogies of those in some other, more familiar phenomenon of the world, or, after repeated survey of similar phenomena, they are specified by means of statistical methods. The mathematical model may help to draw conclusions from the behaviour of some elements of the system (independent variables) on that of its other elements (dependent variables).

In spite of some similarities of terminology, there are fundamental differences between systems concept and mathematical modelling.

They differ first of all in their approach to the problems. The systems concept is a general theory or rather a frame of mind, needing operative tools for practical application. Mathematical modelling is by nature an operative process, capable of solving practical problems within the limits of formal mathematics.

Systems concept and mathematical modelling fundamentally differ in the way how they deal with the problems. Mathematical modelling is restricted to the quantifiable elements and their relations which can be expressed by formal algorithms. Thus, it represents the real world on a certain mechanical level, taking no account of some significant features and the complexity of relations. Systems approach, in contrast, means looking at the whole problem in its complexity, and reckoning with those relations, too, which might be of secondary importance for the purpose of research, and thus confined to the environment of the system.

Systems concept can thus provide a theoretical basis for mathematical modelling, helps to increase the objectivity of the model, make explicit those significant, but non-quantifiable elements and relations, which cannot be represented in the model, prevents the model from deviating from reality while it uses its own rules in the simulation of real-world processes, and finally, determines the way in which the model can be used.

Systems concept can thus be a guiding theory of mathematical modelling, whereas mathematical modelling can be an operative tool of systems concept, a method of the application of this theory in practice.

3. An Example: the Lowry-Model

Mathematical modelling of spatial systems is a versatile tool. It can be an aid in economic decision making, in the study of the social or physical urban structure etc. In the following, this latter, that is, the study of the evolution of physical structure will be considered, although this is undoubtedly only one of the areas of the modelling of urban systems.

In this area the greatest success has been achieved so far, both in theoretical research and in operative practice, by the so-called Lowry model and its derivatives. Therefore, all what has been said about systems concept and mathematical modelling, and the possibilities, application and limitations of mathematical modelling in general, will be demonstrated on this example.

IRA LOWRY published his model in 1964, in the context of the development plan of Pittsburgh urban region. In this model the urban spatial system is viewed as a set of interrelated elements. The elements are the *within place* activities, which exist at a place, and the *adapted spaces* containing these activities, their interrelations are termed *between space* activities, that is, communication flows, and *channel spaces:* transport and other communication networks containing the between place activities. As the model flows, it derives some activities from others, and then — assuming that their interactions are analogous with Newton's Law of Gravitation — allocates these activities to zones. In the assumption that certain activities generate others, the Lowry model, implying some form of the economic base theory, partitions activities as basic and non-basic categories. According to the original theory, basic employment — basic activities being identified as resource and manufacturing industries — includes every kind of industrial, commercial, management etc. export oriented activity which sells most of its goods and services outside the area considered. This sector depends for employment and location on external factors, thus it is the independent variable of the model. From basic employment the number of residents and residential floor space can be calculated (with the help of design standards), and from those in turn service employment and floor space for services. Service employment, however, generates more residents, which, added to the former, generate more services and so on, until basic employment, service employment and residential population reach an equilibrium state.

The model thus uses iteration techniques to determine the number of basic and servicing jobs, employees and residential population as well as the required floor space.

In the allocation of activities to zones, it is assumed that people prefer to live in proximity to their workplaces, and demand services near their homes. Accordingly, two gravity models are used to express workplace-residence and residence-service relations. Gravitation theory suggests that the interaction between two zones is proportional to the intensity of activities in these zones and inversely proportional to the distance separating them:

$$b_{ij} = k \frac{W_i W_j}{c_{ij} B}$$

where b_{ij} = interaction between zones i and j in terms of traffic flows;
W_i = activity in zone i in terms of the number of employees or residents;
W_j = activity in zone j;
c_{ij} = distance or costs of travel between zones i and j;
k = constant;
B = parameter.

If the independent variables are known (W_i, W_j, c_{ij}), the gravity model can be used to forecast the intensity of traffic, thus, traffic pattern can be planned. The same equation can be used as a location model: if the location of activity W_i and transport possibilities c_{ij} are known, the optimum location of activities W_i functionally related to the former can be determined.

In the formal structure of the Lowry model the economic base theory is used to combine two interaction (gravity) models, the constant and parameters of which have to be calibrated according to the actual features of the area under study. The inputs are partly unplanned, "given" characteristics (existing basic employment by zone, existing service centres, proportion of supplied population, activity rate etc.), and partly, planned decisions (new basic employment, new service employment every zone, planned transport network, zoning constraints). The outputs (residential population generated by new basic employment every zone, new service centres, traffic distribution) reflect the effect of a decision on the whole area. By manipulating the plannable inputs, the consequences of proposed strategies can be predicted, thus alternative strategies can be evaluated.

4. Limitations of the Lowry Model

The inadequacies in the structure, variables and performance of the Lowry model are partly of technical nature, and partly arise from the misuse of the model.

The main structural drawback of Lowry-type models is that they simulate the equilibrium state of the system of spatial structure at a single moment. The model can thus be used for comparing different equilibrium states but without showing the dynamics of change. Each time the model is run it generates a spatial system as though the development of the outputs were in response to the initial conditions (the inputs). In reality, however, inputs generating development do not appear simultaneously, and those manifest later may respond to the effects of the first. The performance of the model "compressed" in time is an incorrect simulation of the historical process, and at a perspective the gap between the model and the real world system is likely to deepen considerably.

Another limitation of the model arises from the assumptions of the economic base theory. At a certain stage of social-economic development the location of industries was more or less independent of the geographical distribution of population, and these basic industries generated concentration of population. This, however, cannot be taken for a general rule any more. The model confines generators of growth to the environment of the system and ignores the possibility of growth initiated within the system (by factors such as housing construction, development of services, educational programs etc.) with consequent feedback effect on the amount of basic industry. This means that policies aiming at the growth of basic employment by a better utilization of inner resources cannot be tested on the model.

The assumption that the factor generating a certain activity determines at the same time its location is another shortcoming of the economic base theory. It suggests that people prefer to live in the proximity of their workplaces. This assumption, in view of increasing motorization and communication appears to be an oversimplification. Home-workplace relations are different in the various social-economic groups. Furthermore, it is well known that in our times it is not only the population that is attracted by industrial employment, but the reverse is also true: the availability of labour resources may be decisive for the location of an industry. This "reversed gravitation" is not accounted for by the model. It should be noted, however, that conventional, crude interpretation of the economic base theory is not essential to the structure of the model. Further equations can be added to the model to improve its correctness.

Interactions between activities are interpreted in the model only in terms of inter-zonal traffic flows. This is again too simple. No account is taken, for instance, of the alternative effects of the various modes of transport on land use pattern. Similar simplicity prevails in the allocation of services. Again, not only services are generated by residences, but services themselves (a new shopping centre for instance) may generate development.

The misuse of the Lowry models is partly due to the overestimation of achievements by mathematical models. Quantification and computer techniques are expected to increase objectivity. Every model, however, is based on some theoretical assumption. This implies that the uncertainties of this assumption are quantified rather than eliminated by mathematization. In man + machine systems the man is and will always be the fundamental element: our biases can be quantified but not objectified.

Models risk also to be misused since they depend on calibrated past data, thus their forecasts are trend projections only. The models may therefore exert conservative influence on thinking, implying that there is no alternative except what arises from evolutionary tendencies. Radical social-economic policies may, however, change the way how society works, and these policies cannot be evaluated on the Lowry model.

5. Static and Dynamic Models

Most models built so far use analytic methods in their approach. They involve mathematical analysis to examine the repercussions of the change of an element over the whole system. In other words, the models represent the structure of the system at one cross-section of time without recourse to any explanation of the changes in the structure over time. The process of changes over time, when the system responds to external stimuli to finally return to an equilibrium condition, is the behaviour of the system. Without simulating the dynamics of change the model remains incomplete, because the system structure cannot be interpreted without the knowledge of system behaviour. This proposition involves dynamic modelling of spatial systems, the integration of system behaviour and system structure. The construction of such models, however, is made difficult by the great data requirement and increased costs of computerization as well as by the fact that the behaviour of urban systems is largely unknown and extremely difficult to observe. This is why — although most current operational models contain some implicit measure of system behaviour — the building of dynamic urban models is at an initial, experimental stage and has not produced verified results yet. The early experiments of dynamic modelling of urban systems, introducing the time dimension in modelling procedures, are based on unverifiable hypotheses. The dynamic interpretation of the Lowry model, for instance, suggests that the change of the independent variable (that of basic employment) is followed but gradually, in the course of a so-called "relaxation time", by the appropriate change of dependent variables. Consequently, these latter take incremental changes, to gradually reach their final value, and this process can be represented by a function. Such methods are familiar in the modelling of economic processes.

Dynamic models thus try to answer a twofold question: *what* is the outcome of changes, and *how* these changes occur. The first refers to system structure and the second to system behaviour.

6. The Use of Models in the Planning Process

The Lowry model owes its success to several of its features. It can be used as an operative, planning method, has a simple logical structure which can be modified (that is why it has many derivatives), and is simple to construct in terms of data requirements. Therefore in the families of models of spatial systems built so far, the Lowry model or one of its derivatives is the most frequent central element.

In discussing the uses of models it should be determined first of all in what scale their application promises the best results.

In principle, there is no limitation in terms of scale of the application of the models. The boundaries of the spatial system can be arbitrarily established if external relations are interpreted as those prevailing between the system and its environment. Models have thus been built on both regional, and town (of 500,000 or even less) scale. Experience shows, however, that in the latter category the performance of the model requires a multitude of complicated data, which greatly increases the costs of performance and makes it difficult to test the model against reality.

A partial problem (like transport or retail network) can be modelled on any scale (including that of a small town or district), but it can be generally stated that the more comprehensive the model is from functional point of view (integrating land uses and networks, considering technical, economic and social problems) the more difficult it is to build it at a small scale or to dissect it to small area units.

The upper limits of the scale need not be identified. It only depends on the maximum area with relations comprehensible to the model builder. In the preparation of a national regional plan (especially for a country with the dimensions of Hungary) mathematical models can be used with success. There is no doubt, however, that comprehensive models at the national scale are relatively seldom needed.

The most promising field of the application of functionally comprehensive mathematical models or families of models — such as the Lowry model — is regional planning. In this case the modelled spatial system is an economic region or sub-region (metropolitan area), where the spatial units grouped around one or more centres are functionally interrelated, and owing to their common geographical, economical and social characteristics, form an integrated entity. The boundaries of such spatial systems are not arbitrary, because their inner relations are more intensive than the external ones. Regions or their components, the sub-regions, agglomerations or metropolitan areas are to be regarded as integrated entities because of the tendencies of contemporary urban development too: deconcentration on the urban scale (that is, desintegration of the town as the basic element of settlement structure) and concentration on the regional scale are world-wide phenomena of urbanization. This tendency has been recognized in most countries as reflected by the national statistical surveys where agglomerations or metropolitan areas are treated as units, facilitating data collection for modelling.

Modelling of spatial systems may serve several purposes. They can be used to study the structure of some urban system and the tendencies of its evolution. Such models may be called *descriptive models.* Furthermore, models can be used in the actual planning process, in the examination of the consequences of proposed strategies. This operation may be in two stages: first, individual strategies may be tested against resource constraints and design standards. In this way the feasible strategies can be selected. In the second stage the outputs of feasible strategies are confronted. After this evaluation either the optimum strategy is selected, or new alternatives combining the best features of evaluated strategies are elaborated, and the model is run again. Thus, models can be used for the purpose of *evaluating* the effects of planned changes.

In the same way the model can be used to test the impact of uncontrolled changes (unforeseen changes in basic employment or population, building of a major transport facility or a new town) on the spatial structure. These changes may occur spontaneously or may result from a central decision. This *impact study* enables the planner to keep track of the major developments in the region, link them up with the previous forecasts and planning decisions, and reckon with them in the planning process.

This latter is really a part of another important field of the use of models, the process of continuous *monitoring*. This means that by running the model at frequent intervals a close watch can be kept on the gradual changes in the state of the region, to measure the impact of implemented policies, to re-forecast with new data, to identify emerging problems, and to evaluate trends against the objectives of the plan.

It follows from the former that the application of mathematical models, that of the Lowry model in particular, can be useful in the elaboration of the so-called structure plans, dealing with the broad structure of an area and with the principal policies for growth and change, somewhat similar to the programs of general plans used in Hungarian practice. Structure planning preceeds physical planning, the graphic representation of planning policies, but it is never confined to a single period of time. The control of the dynamics of change requires *continuous* — cyclic — *planning process* with special emphasis on continuous monitoring and flexibility of decisions. Actually, planning is expected to perform modification, continuous control of the urban structure in response to changes and social demands rather than to design a desirable state of the environment.

Conclusions

Mathematical modelling of urban systems has become a useful method of urban studies and planning. In this process, where the part of mathematics is growing in the solution of urban problems, the adoption of the systems view gets ever more important.

Mathematics can model the processes and relations of the real world, thus representing — like any other model — phenomena other than itself. Owing to this capacity, it can simulate real world phenomena and processes comprising them in both time and space. This is why mathematization develops into an important method for the science and practice of urbanism, but this same capacity involves serious dangers. The mathematical model of the urban environment may become "independent", transforming input relations and generating development trends according to its own rules, and owing to its quantified data it appears to be objective even if the trends generated by the model do not replicate the real world processes accurately.

It is therefore of great importance to select the appropriate variables and their appropriate relations in model building. At this critical, initial stage the systems view can be a useful aid, for it provides methods which increase the objectivity of the approach, describes the nature of relations even if they cannot be expressed with formal mathematical algorithms, points to the neglected factors, and identifies relations of the system with its environment. Consequently, if mathematical models "quantify our biases", the systems approach helps to increase the objectivity of assumptions.

Furthermore, systems view is important in the application of mathematical models, especially in the application of planning models in those cases where the task of planning is not the control of an "action" limited to a certain area and period of time (e.g. the redevelopment of a relatively small area, or detailed physical planning in general), but the channelling of urban growth and change (the so-called "general planning").

If the models constructed with this purpose are based on information about the system structure and behaviour at a given period of time they are deterministic, representing a closed system, and will determine development in a subjective way rather than to control growth and change.

Human environment is in contrast an open, evolving system, thus its future state cannot be deduced from that taken at a given cross section of time. Therefore it is necessary to build simulation models which are in continuous contact with the simulated system (the real world), and which in response to the new information are capable of changing their behaviour.

All this means that the control of changing human environment involves continuous planning of strategic type continuously adapted to the changing conditions rather than subsequent phases of planning and realization.

Systems approach indicates that the construction of dynamic models integrating system structure and system behaviour is needed for the simulation of complex and continuously changing processes. Such models must operate in the above described manner, thus, on the basis of a continuous flow of information between the model and the real world, and integration of new trends and processes with the simulated ones. Mathematical models are essentially used for forecasting. Forecasts (the assumed, future state of the system), however, have to be tested against reality by means of continuous feedback. This is especially important in the modelling of human environment — urban systems — because in this field the tendencies of change are but vaguely known.

The major use of mathematization in urban planning practice is that it provides relatively simple techniques for the construction of such dynamic models.

Summary

In urban studies and planning, mathematical modelling is a useful aid facilitating to forecast the effects of change in one element of the urban system on its other elements. Models can thus be used for the investigation of the structure and behaviour of urban systems, evaluation of planned strategies, testing the impact of uncontrolled changes, and continuous monitoring, in short, in the cyclic process of structure planning.

The success of the application of mathematical models largely depends on whether the theory underlying model building is adequate for the purpose of modelling. In the selection of the appropriate theory, in testing the model against reality, as well as in the determination of the ways in which the models can be used, systems approach is inevitable.

References

1. Batty, M.: An Experimental Model of Urban Dynamics. Town Planning Review, Vol. **43**, No. 2. April 1972.
2. Batty, M.: Recent Developments in Land-Use Modelling: A Review of British Research. Urban Studies, Vol. **9**. No. 2. June 1972.
3. Echenique, M.: A Model of the Urban Spatial Structure. Architectural Design, Vol. **41**, May 1971.
4. Lowry, I. S.: A Model of Metropolis. RM-4305-RC, RAND Corporation, Santa Monica, 1964.
5. Massey, D. B.—Cordey-Hayes, M.: The Use of Models in Structure Planning. Town Planning Review, Vol. **42**, No. 1. January 1971.
6. Meggyesi, T.: Modelling of Human Environment: A Systems Approach.* Építés- és Építészettudomány, Vol. **3**. No. 2—3. 1971.
7. Meggyesi, T.: Urbanism and Systems Theory.* Demográfia, Vol. **14**. No. 1—2. 1971.
8. Perraton, J.: Towards Models for Urban Structure Planning. Journal of the Royal Town Planning Institute, Vol. **58**. No. 7. July/August 1972.
9. Taieb, F.—Di Meglio, P.: Un modèle de localisation des surfaces commerciales: Paprica. Urbanisme, **40**e Année, No. 126. 1971.

Senior assistant Tamás Meggyesi
Research worker Mrs. E. Vajdovich-Visy
1111 Budapest,
Műegyetem rakpart 3
Hungary

---

* In Hungarian.