ON SOME MAJOR SYSTEMS' PROPERTIES

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I. Introduction.

Any process of System Modelling (in either mathematical or simulation studies) goes through several basic stages, shown by the diagram of Figure 1. Even though each of these stages has its own importance the most crucial is however a system specification as a background for all other stages.

When one specifies a system he obtains an initial macro-model of reality giving a first approximation to the understanding of the essential characteristics of the systems being studied. All other stages of modelling are aimed at giving more details on general systems behaviour and at separate specific features of the system as well.

The paper discusses a set of general system properties which can be used as macro-properties in systems specifications. To make the discussion more illustrative the general system properties are presented through the descriptive definition of the two classes of systems: primitive systems and complex systems. These classes do not exhaust all varieties of practical systems, but rather identify limiting cases which encompass the whole spectrum of other systems.

Though many of the macro-properties are well-known, as being pertinent to real systems, the question still remains, "Do existing models account for them?"

The results of comparing the suggested macro-properties against properties of models of compex urban systems are given to show that the answer is more often "no" than "yes". These results are indicative and similar also in another respect. They display black spots, i.e. system properties which are not represented in any of the models. On the other hand, they show a way of integrating properties and building good synthetic models of complex systems.

Before proceeding with further discussion, a look at the general control diagram of Figure 2 may be useful. This diagram displays the basic elements of a control system: the measuring unit (MU), the control unit (CU) and the controlled system itself (S) and shows the principal channels which provide the interaction among the basic elements. Border lines are drawn to separate the elements of a control system from one another and to separate a controll system itself from the "rest of the world", called environment (ENV).

A further generalization of the diagram must include the systems analyst (SA) in Figure 3 because his actions may strongly influence a system behaviour and vice versa. Although the diagrams shown are pertinent to all "control situations", the specification of their elements and interaction channels is not a trivial task and often requires time and labour-consuming procedures. Moreover, in many cases the complexity of the problem does not give even a slightest hint for finding a solution. As a result, the diagrams of Figure 2 and Figure 3 are chiefly illustrative and are applied as a useful convention. However, their effectiveness can be increased by using them for purposes of systematization and structuring macro-properties of the real systems.

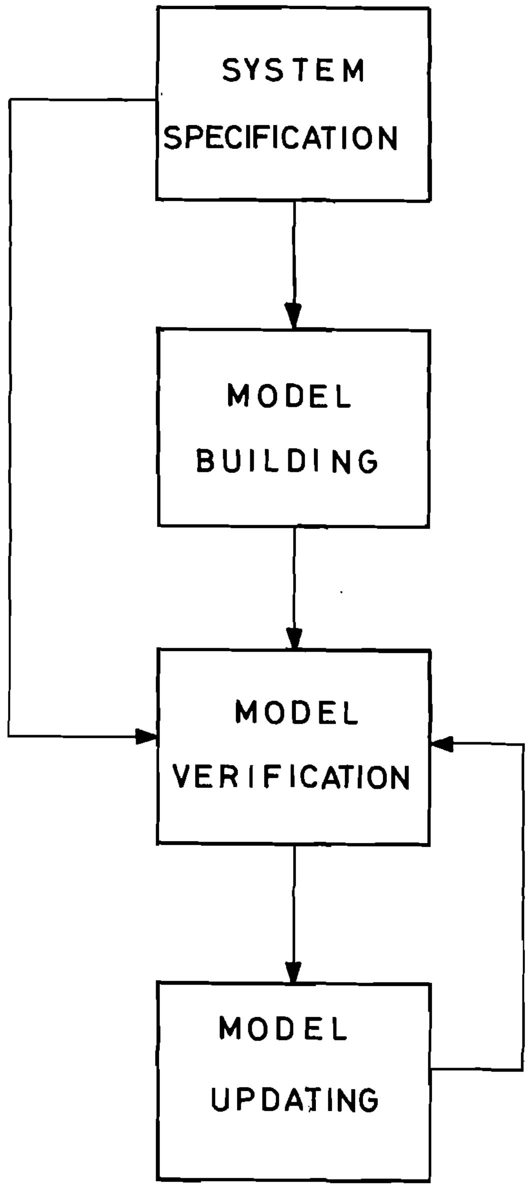

FIGURE 1. BASIC STAGES OF SYSTEM MODELLING.

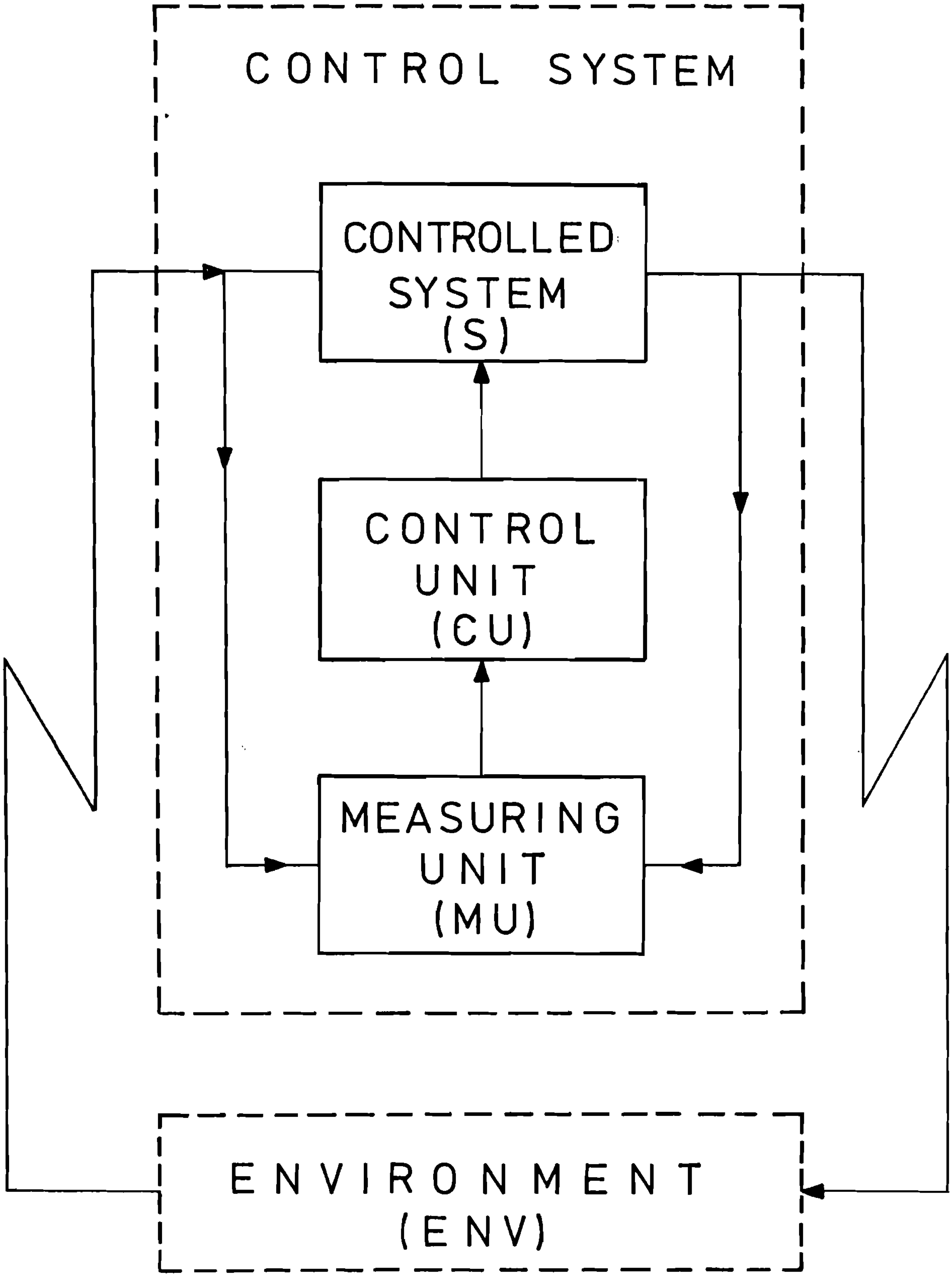

FIGURE 2. STANDARD CONTROL DIAGRAM

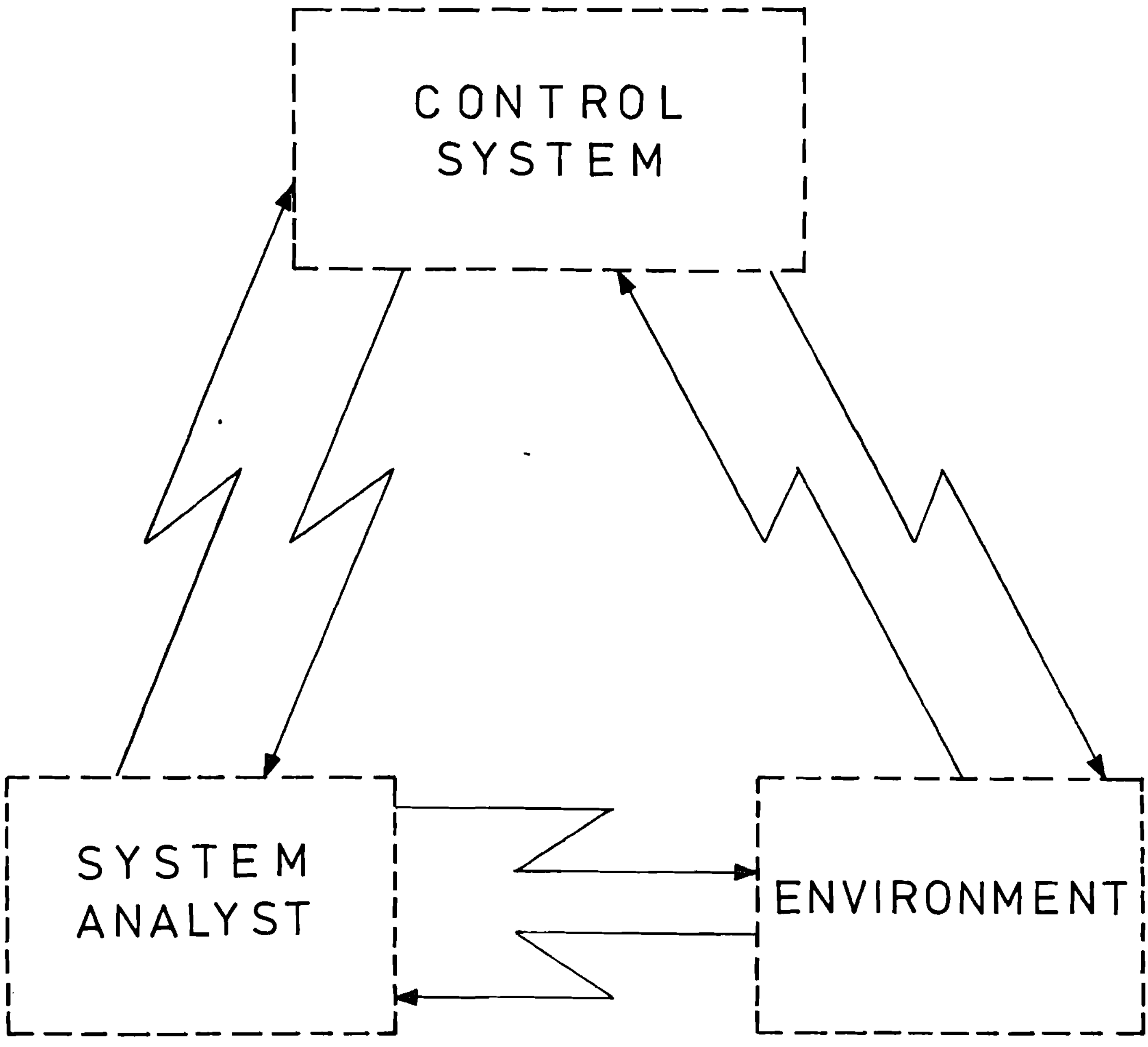

FIGURE 3. GENERALIZED CONTROL DIAGRAM

II. Description of general systems properties as related to two extreme classes of systems.

Note at the outset that properties of basic elements of the general control diagram, modes of interaction among them, characteristics of interaction channels and border designations are not constant and may vary from system to system. Bearing this in mind, let us try to identify two extreme classes of systems ordered by increasing complexity of the appropriate variables. In deriving this description we shall keep to the natural grouping of the properties given in the general control diagram.

1. Primitive systems.

We shall define a control system as belonging to the class of primitive systems if it displays the following properties:

Properties of Elements

- The controlled system (let us call it "system" for the sake of simplicity) can be well defined, i.e. all Inputs and Outputs can be presented as certain sets of deterministic variables, as well as explicit functional relationship between Inputs and Outputs given.

- The system is functionally stable. It does not change its function appreciably over time. (Although, some performance degradation on intentional external variations may take place).

- The internal structure of the system is strictly given and does not evolve (slight minor variations are admissible).

- The system is deterministic in the sense that each set of Input variables is strictly related to one set of Output variables.

- The systems dimensions are not so complex as to preclude systemic behaviour from being analytically or algorithmically studied.

- Goals are given to S, MU and CU from the outside and stay constant over time. No private or internal goals exist.

- Input and Output variables can be measured with an accuracy defined by the MU. (Theoretically with any accuracy). So the control problem is solved with meaningful accurate data.

- Control actions can be analytically or algorithmically defined and (most importantly) implemented without major difficulties. It is noteworthy that the system does not affect the implementation of control actions.

- The results of control actions can be easily predicted. Moreover, these results can be physically measured, properly interpreted and evaluated within a reasonable amount of time. Time constants for S, MU and CU are not unduly large.

Properties of Interaction Process

- The system functioning does not affect the environment very much in that the environmental properties remain unchanged (Cumulative effect of interaction may be an exception, however). The ENV exhibits absorption properties relative to the system behaviour.

- The interactions between S, MU and CU are not antagonistic, because the goals allotted to S, MU and CU are carefully matched by the systems designer.

Properties of Borders

- Properties of these four elements (Figure 2) generate an identifiable border (interface) between the System and Environment. On demand, the systems analyst (SA) may indicate the border position with good accuracy. Once established, the position of the border line does not change over time.

- The borders between S, MU and CU are also established in a concise and clear-cut way. They are well defined in the sense that MU and CU have no internal goals which can interact with the goals of the system.

- Although system may be physically combined with MU and CU, the identification of the border lines may nevertheless be done on the basis of functional criteria.

General Properties

General properties may often overlap with some of the properties listed above, but to conserve space, let us consider only additional general properties.

- Certain properties of system elements, (border lines and interaction processes) make analyses and syntheses problems for such systems solvable in a reasonable way.
- The control system (CS) has a one-dimensional performance criterion as a rule.
- Physical experiments can be made with the system itself (as well as with its models) without leading to inadmissible expense.
- Cost-benefit analysis can be easily applied to these systems since all the necessary parameters are readily available.
- The systems analyst is not a part of the system in that the system's behaviour does not produce a pronounced effect on the systems analyst.
- Investigating properties of the primitive system allows us to draw the following general conclusion: Primitive Systems are well defined, and their control problems are "proper", both theoretically and practically. Indeed, since the systems analyst is outside of the system he may generate the necessary and sufficient hypotheses about the system and its Environment and build a logically consistent control theory. At the same time he has (or can obtain) all relevant data with required accuracy to solve the control problem both theoretically and practically. To illustrate the concept of the Primitive Systems, typical elements studied by the classical control theory may serve as examples, (e.g., level controllers, servo-drives, etc.).

2. Complex Systems

Let us start to describe this class of systems with the major premise. The Control problems for this class of systems are "non-proper" both theoretically and practically. To demonstrate this premise, consider a set of properties basic to complex systems.

Properties of the Elements

- The system can be defined only in a very loose sense, i.e. Input and Output can be represented only by stochastic variables and the relation between them is also stochastic.

- The System is capable of generating its own internal goals which can define system behaviour, but at a rate comparable to or even higher than the external goals. Availability of internal goals results in <u>active nature</u> of the S behaviour.

- The presence of internal goals makes the system functionally changeable. This means that what the systems analyst believes to be the <u>same</u> system over time, may actually be a series of different systems from moment to moment. The prediction of future functional properties of the system is made a challenging task therefore.

- While remaining within the same functional bounds, the presence of internal goals may enable the S to change its structure toward a more efficient attainment of its goals. Such structural changes may often happen without the participation of a systems designer.

- Goal multiplicity is very characteristic of complex systems. These goals are not usually well isolated but interact in a rather sophisticated way. Such interaction may produce new goals as output. The goals are difficult to express in a quantitative way, but are usually formulated as qualitative judgments.

- As a rule, the system has high dimensionality. Moreover, it consists of components, many of which have different physical natures. These features complicate in the analysis of system behaviour even if algorithmical methods can be used for the analysis.

- The MU and CU may also have their own internal goals -- ones which do not necessarily coincide with those external goals set by the systems-designer.

- The MU and CU are essential components of the system itself, so the success in the attainment of their individual goals depends very much on the general system goals attainment.

- Because of the high inherent system complexity, proper control actions are difficult to develop.

- Another aspect of the same problem is that implementation of control policies do not necessarily produce the desired results. Good control policies do not always yield the expected good results. On the other hand, (and depending on the system's own attitudes toward control policies), the results desired may be readily obtained via controls which differ greatly from the optimal ones.

- The overall system time constant exceeds not only the time constants but sometimes even the life times of component parts. This adds considerable difficulty to both data measurement and control implementation. This together with that of functional variability may create time lag situations where present-time control measurements can be compared only as related to the systems specifications as of the time when the controls were initiated.

- There are serious problems not only in measurements of controls results but also in their prediction.

Interaction Process Properties

- The S is not invariant to actions of the MU. The system evaluates these actions, tries to restore MU goals, maps these goals against its own and report data which depend on the accuracy of this mapping. But the accuracy of such data depend not only on the MU accuracy but also on the interaction process between the MU and the S, hence again complicating accurate system analyses.

- Since the CU is not invariant to the S behaviour, there are additional constraints on the range of feasible control policies, particularly if a strong feed-back between S and CU performances exists.

- The system's own functioning may produce pronounced environmental effects, resulting in feed backs between the system and the environment.

Border Line Properties

- There is no a-priori border line between the S and the ENV. It is conditionally set by a systems analyst and may be changed.

- Neither are there fixed border lines between the S, the MU and the CU. They are frequently fuzzy and may vary in the course of S functioning.

General Properties

- The overall system has homeostatic properties, i.e. system equilibrium states are positioned very close to each other so that even large (but not catastrophic) disturbances manifest themselves only by pushing the System from a current equilibrium state to a nearby one.

- The overall system has a multi-dimensional (vectoral) performance criterion, which frequently cannot be expressed in a quantitative way only qualitatively.

- Serious difficulties arise in arranging physical experiments with the real system. They usually require too much time labour, money, etc. Consequently, experiments are possible only with system models and only then provided they are adequate,

- Cost-benefit analyses cannot be carried out at a rigorous level since not all relevant functions and data are always available.

- A system analyst is himself a part of the overall system in that his goals interact those of the system's MU and CU. Judgments about the system are strongly affected by this process of goals interaction. Therefore, it follows that a control problem for a complex system is "non-proper" theoretically. Indeed, to formulate an initial set of hypotheses about the overall system behaviour we must introduce a metha-systems analyst. But he is also a part of the system. As a result, it is impossible to build a logically consistent theory because some part of the system must necessarily be expressed in terms of its own meaning. On the other hand a control problem even if formulated in some way happens to be solved with inaccurate data (with estimates of the parameters rather than with their real values). Thus, the control problem for complex systems is "non-proper" both theoretically and practically.

- Any human organization may serve as an example of the complex system concept.

III. Relation of general system properties to macro-properties of some models of complex systems.

As illustrated by the previous section there exists a set of macro-properties which may be used to show the difference between systems.

These properties do not look too abstract but rather represent the real factors defining the diversity of real systems behaviour, so they may be used at the initial stage of systems specification.

Bearing in mind the utmost importance of some of the properties for real systems let us try to identify whether the existing models do have many of them.

Rather than looking through the whole lot of existing models which seems unfeasible, we will restrict ourselves to the consideration of only one class of models of urban dynamics, which no doubt is related to the complex systems class under the previous classification, and hence should exhibit the majority of the properties.

The degree of accounting for the major macro-properties of systems in 10 models of urban dynamics is summarized in the Table; the columns represent the properties, while the rows -- the names of the models. Note that the specific meanings of the entries in the table are not set very accurately but instead are used as conventional indicators; if there is a "yes" entry it should be understood as being more "yes" than "no" and vice versa. The presence of a "yes" also signifies that the respective property was given some consideration at any rate, during the model design stage, but does not give an idea of the success of its final implementation in the model.

Even under such weak assumptions, the Table does not look promising in terms of presenting many important macro-properties of systems in the models.

On the contrary there are many columns full of "no"'s. For example though goal multiplicity is given some consideration in the models, the problem of goals distribution among the elements of the system implementing different functions, the nature of the goals (internal or external), the mechanisms of goals matching are practically outside of the model's scope. As a result some very important problems that arise in practice due to the presence of internal goals in elements measuring the data in systems, elements generating control policies and elements implementing controls, are not given proper attention at the stage of models design. The same statement is pertinent to the problem of interaction as it applies to the systems analyst and the system. None of the models presented in the Table accounts for the environmental effects produced by the system and for the presence of internal homeostatic properties in real systems. Both of these factors are often of crucial importance. The former one results in raising powerful feedback loops which affect the goals of the system and may introduce essential functional and structural variations. The latter ensures system controllability even if it looks hopelessly complex.

In spite of the majority of negative entries, the Table may still be useful. In fact it stimulates two ways of thinking. First of all some of the models do not intersect in terms of the macro-properties that they account for. This means that there may be a good way to integrate several macro-properties in a single model and build a synthetic model, whose pattern of behaviour approaches closely that one of real systems. This idea has further support from the fact that not all of the techniques available are used in the models under discussion, to represent the useful macro-properties. In particular several good principles of goal matching are known which could be used to advantage in models of that type.

TABLE: COMPARISON OF MACRO-PROPERTIES OF REAL SYSTEMS AGAINST THE MACRO-PROPERTIES

AME OF A MODEL ND/OR AUTHOR	ACCOUNTING FOR: RANDOM BEHAVIOR	INTERNAL GOALS	FUNCTIONAL CHANGES	STRUCTURAL CHANGES WITHOUT PARTICIPATION OF DESIGNER	ACCOUNTING FOR: GOALS MULTIPLICITY	HIGH DIMENSIONALITY	INTERNAL GOALS IN MU AND CU	CONTROL POLICY IMPLEMENTATION OF MECHANISMS	LARGE TIME CONSTANT OF A SYSTEM	MEASUREMENT OR PREDICTI OF THE RESI OF CONTROL
OM I, II, III CRECINE)	NO	NO	NO	YES	IMPLICIT	AGGREGATE DATA	NO	NO	YES	YES
ORTH CAROLINA MODEL CHAPIN ET AL)	NO	NO	NO	NO	NO	AGGREGATE DATA	NO	NO	YES	YES
EMPIRIC HILL ET AL)	NO	NO	IMPLICIT	IMPLICIT	NO	AGGREGATE DATA	NO	NO	IMPLICIT	YES
CTIVITIES ALLOATION MODEL SEIDMAN)	NO	NO	NO	NO	IMPLICIT	AGGREGATE DATA	NO	NO	YES	YES
NDUSTRIAL DYAMIC TYPES ODEL FORRESTER ET AL)	NO	IMPLICIT	NO	YES	YES	YES	NO	NO	YES	YES
ACROECONOMIC PAFLINCK ET AL)	IMPLICIT	IMPLICIT	IMPLICIT	NO	NO	AGGREGATE DATA	NO	NO	YES	YES
ESIDENTIAL EMOGRAPHIC WILSON)	NO	NO	NO	NO	IMPLICIT	AGGREGATE DATA	NO	NO	YES	YES
OLIS 1,2 J. MEISE, . WEGENER)	IMPLICIT	NO	NO	NO	IMPLICIT	IMPLICIT	NO	NO	YES	YES
ODEL OF URBAN DYNAMICS M. BATTY)	NO	NO	NO	NO	NO	AGGREGATE DATA	NO	NO	YES	YES
LAND USE AMING SIMULAION SYSTEM I. TAYLOR)	YES	YES	NO	YES	YES	AGGREGATE DATA	IMPLICIT	NO	YES	NO

TABLE: COMPARISON OF MACRO-PROPERTIES OF REAL SYSTEMS AGAINST THE MACRO-PROPERTIES OF SEVERAL MODELS OF URBAN DYNAMICS

ACCOUNTING FOR				ACCOUNTING FOR			
SYSTEM RESPONSE TO THE MU ACTIONS (ACCURACY OF MEASUREMENTS	CU RESPONSE TO A SYSTEM BEHAVIOUR	INFLUENCE OF A SYSTEM ON THE ENVIRONMENT	FLEXIBILITY OF BORDER CONDITIONS	INTERNAL HOMEOSTASIS	VECTORAL PERFORMANCE CRITERION	COST-BENEFIT CONSIDERATION	INTERRELATION OF THE SYSTEM ANAL AND A SYSTEM
NO	NO	NO	IMPLICIT	NO	NO	NO	NO
NO	NO	NO	NO	NO	NO	NO	NO
NO	NO	NO	NO	NO	NO	NO	NO
NO	NO	NO	NO	NO	NO	NO	NO
NO	NO	NO	YES	NO	IMPLICIT	NO	NO
NO	NO	NO	NO	NO	NO	NO	NO
NO	NO	NO	NO	NO	IMPLICIT	NO	NO
NO	NO	NO	NO	NO	IMPLICIT	NO	NO
NO	NO	NO	NO	NO	IMPLICIT	NO	NO
NO	NO	NO	IMPLICIT	NO	NO	NO	NO

It is noteworthy that the gaming simulation approach looks promising in terms of accounting macro-properties of real systems. The gaming model set in the last row of the Table seems to be much richer as compared to all other models.

Secondly, columns whose entries are all negative may identify important direction of further research which have not so far been given proper attention.

Conclusions

A very important stage of any systems modelling, in either mathematical or simulation studies, is systems specification.

Several macro-properties of systems are discussed which can be used to advantage at this stage.

The properties are illustrated through their application to specification of two extreme classes of systems: primitive systems and complex systems. The same application demonstrates that the properties under discussion may provide a good distinction among systems at a macro-level.

The question was raised "Do the existing models or complex systems account for many of the important macro-properties of real systems?"

An attempt to answer the question was undertaken by comparing the macro-properties under consideration against the macro-properties of several models of urban dynamics. The results of the comparison showed that the answer to the question is mostly negative.

The Table summarizing the results may find another useful application. Provided it includes a great number of the most important models in urban systems it may lead to a good synthetic model which would exhibit the majority of the macro-properties implementable within the limits of the available techniques.

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