A PERSPECTIVE FOR THE STUDY OF SOCIAL AND URBAN SYSTEMS

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Summary

An approach to the study of large and complex systems, in which the complementary properties of structural and behavioral characterizations are used to provide a unified framework to meet the needs of design documentation, mathematical analysis, and simulation, is discussed in the light of its applicability to social and urban systems.

Introduction

The study and analysis of social and urban systems embodies a blend of behavior and structure. Attention to behavioral attributes assures studies which adequately reflect the function of the system, but which do not account for structural limitations on system behavior. Thus, the political candidates in the DeKalb model[1] have idealized campaign organizations not subject to the usual limitations of bureaucratic delays and uncertainties. The Carnegie Tech management game[2] does not replicate the interplay between various organizational functional blocks other than those in management. And it is doubtful that many of the myriad of war games would have predicted the recently publicized apparent breakdowns in military reporting procedures and resource deployment.

Conversely, studies which emphasize the structure of the system of interest do not necessarily provide results which relate to a useful perspective. Queuing delays at particular points in systems do not necessarily directly indicate overall transit times. Similarly, particular transit times do not by themselves provide sufficient information if, as is often the case, one is interested in their values relative to the ensemble of pertinent transit times. In general it is a valid reservation to maintain that most structural models, queuing networks, traffic flow, population dynamics, and the like, pose some difficulty in maintaining the desired global perspective, to the extent that thoughtful critics, such as Lewis Mumford,[3] have questioned their usefulness.

This problem is neither unique to social and urban systems, nor to simulation development. It is common to all large systems studies, including the areas of documentation, mathematical analysis, as well as simulations, that it generally requires much more effort than it should to relate various studies and analyses to one another and to extract meaningful issues and parameters from a given description of the system. An approach found useful in the development of a workable perspective has been described elsewhere.[4] The purpose of this paper is to review the applicability of this framework to the study of social and urban systems. The approach is outlined in the next section, and the applicability in the context of documentation, analysis, and simulation is discussed in the following three sections.

The Approach

The problem as stated is one of maintaining a balanced perspective between behavioral and structural characteristics of a system. The approach taken to meet this need is to employ two different system characterizations in a manner which exploits their complementary nature. A behavioral characterization needs some accounting for system structure in order to include realistically the system operating constraints. On the other hand, a structural characterization needs behavioral or functional guidelines in order to relate system operation to issues of general interest.

From a structural view, it is possible to characterize a system as a network of functional blocks. The actual nature of these blocks varies from one system to another and, indeed, within a given system. If the system of interest is a transportation network, then the blocks would generally be sectors in the area served by the transportation system. If the system were an organization of some sort, then the blocks would probably correspond to the meaningful organizational entities as well as certain physical facilities contributing to the operating characteristics of interest, such as time delays. In general the particular choice of blocks is application dependent, so that beyond the need for lending precision to the development, there is little usefulness in cataloging possibilities.

Aside from not relating directly to the systems issues of general interest, the structural network poses another, practical difficulty that such characterizations are not normally provided in any detail. This in spite of the proven usefulness of road maps in expediting transportation. The most detailed descriptions are usually provided for the functional blocks, their operation, functional responsibilities, inputs, and outputs. These descriptions may or may not be consistent over the entire structural network. This inconsistency occurs more often than it should even at the obvious level of inputs and outputs; at the deeper level of assuring adequate time and information to perform the desired functions within the blocks, inconsistencies are virtually certain in any moderately complex configuration. Although the discussion here is directed primarily toward organizations, traffic flow systems are equally susceptible, though more often remedied since the effects are more apparent physically.

In general the assurance of a consistent, compatible, and balanced design over the entire structural network requires a prohibitive amount of time and energy. However, an even more fundamental question is to determine what constitutes an adequate amount of system resource (time, information, etc.) for the proper functioning of each block. This question cannot be addressed in the context of the structural network alone; it provides the primary motivation for the following behavioral characterization.

The behavioral characterization employed consists of a set of actions which the system must execute. The actions are defined operationally in terms of the path (or path ensemble) which must be traversed in the structural network to complete the action. The actions normally define system activity which transpires between significant events. Thus in a law enforcement system one action might be the detection-apprehension sequence, which begins with the detection of a crime and ends with an arrest. In an air pollution control system one action might be the critical pollution level sensing sequence, in which an outlying sensor detects a pollutant level exceeding a threshold, relays this information to a central data processor which makes further checks to determine whether the pollutant level, taken together with other available information, constitutes a critical condition. In transportation systems, actions of interest would correspond to the transferral of commodities between various points of interest. In an airport terminal, the actions of primary interest would normally correspond to transporting passengers and baggage between various points in parking lots and various loading ramps.

Having outlined and motivated the approach to system characterization, consideration now turns to its applicability to social and urban systems. The development proceeds in turn through the three activities of documentation, mathematical analysis, and simulation.

System Documentation

The documentation implied by the system characterization discussed in the last section consists of a graphical display of the paths which define the actions in the action set. A meaningful set of actions may range from ten up to a hundred for a reasonable range of system size and complexity. The representation found useful and convenient is illustrated in Figure 1 for the action outlined above in the air pollution control system. The merit of a succinct graphical characterization of system operation is that it provides all interested parties, clients and analysts, with an appreciation of the structural limitations on the implementations of various actions of interest. This is essential if one is to judge whether the system is responsive to the proper needs. It would seem to be of decided value to a citizen to know that his government has a procedure defined whereby his particular needs can be assessed, interpreted, and then acted upon where appropriate, and to have some appreciation moreover of the response times involved.

For the analyst the paths provide an immediate point of departure for addressing questions concerning the appropriate definition of the procedures (paths) and the distribution of diverse system resources, such as information, time, power and authority, computing capacity, and so forth. For example, in the context of the path shown in Figure 1, one may ask whether the functional block Pollution Level Evaluation has been provided with sufficient information to determine the criticality of the pollution level, or one may ask whether Pollution Control has been provided with both the necessary authority and the wherewithal to implement effective pollution control once a critical pollution level is sensed. In the author's experience, these questions have proven to be worth asking.

Mathematical Analysis

The analysis discussed in the preceding section might well consist of either mathematical reasoning, computer studies, or even experimentation. However, it is of a limited scope because generally only one action is considered at a time. Once the set of paths has been reasonably well defined, the formulation of two classes of mathematical programming problems follows immediately. The first provides a global approach to the question of system response times. The basis for this formulation is the observation that the response times of the actions can be written as linear functions of the response times of the individual functional blocks, the equations being derivable directly from the paths. The next observation is that the only meaningful performance specifications must be placed on the action response times, not the block response times. Performance specifications then provide a set of linear inequalities bounding the functional block response times collectively from above. Within this minimal framework, certain preliminary analyses to evaluate the reasonableness of the performance requirements are possible.[4] In general, however, one needs an adequate characterization of implementation constraints in order to proceed further. Essentially, the question is to determine what collective constraints bound the functional block response times from below. A separate constraint is to be determined for each system resource, e.g., channel capacity, computing capacity, road-building funds, personnel effort, which is to be allocated among the functional blocks. The allocation of computing capacity among several blocks serves to represent the type of constraint encountered. Assume that the number of instruction executions required to produce a response to any stimulus is n_i for the i-th functional block, while the response time is t_i. The combined instruction execution rate of all the blocks cannot exceed the instruction execution rate of the data processor, denoted R. This implementation constraint is then written as

$$\sum \frac{n_i}{t_i} \leq R$$

A linear approximation is required, of course, if the linear programming framework is to be retained. Refinements can be made to provide for dedicated processing, multiple processors, and so forth. However, the point of interest here is that in most cases any model of implementation constraints will require validation by either tests or simulation. Thus a clearly defined role for system simulation emerges in a manner that serves to complement analyses of other types.

At the beginning of this section two classes of mathematical programming problems were mentioned. The second class concerns response reliabilities and leads to a geometric programming formulation. Note that the probability that an action is completed is expressible as a posynomial in terms of the individual block reliabilities. Having identified the posynomial terms, a geometric programming formulation follows immediately.[5] Since no applications of this formulation have been made to date, further discussion is not warranted.

Simulation Studies

Throughout the discussion in the previous sections we have mentioned ways in which simulation studies may support various other activities. Now let us consider the development of simulation studies in their own right. The basic characterization in terms of the actions and their defining paths through the system functional network is probably most directly relatable to discrete simulations. The functional blocks would normally identify directly with GPSS facilities or storages. Alternatively, the initiation and completion of the various actions should correspond to significant system events, as noted earlier. For interactive or gaming type simulations, the action set and the paths define in a succinct manner the roles of various functional blocks and highlights the nature of their interactions with other blocks.

To provide the basic information needed to structure a simulation is, of course, a minimal requirement. What seems more significant is the manner in which the information is organized. When the functional roles of the various blocks are defined in terms of the actions, an approach to system simulation is suggested which provides selective bridges across the spectrum of simulations from the abstract functionally oriented simulations to the detailed replications of structure. Since a complete simulation replicating both function and structure is out of the question for systems of any size or complexity, selectivity is essential. By constructing simulations in this manner we are therefore in a position to make selective investigations of the manner in which the structure of a political organization affects the performance of a candidate or to examine the interaction between production and management in the context of selected production decisions and reporting procedures. These questions do not seem to be conveniently addressable in the context of the DeKalb model[1] or the Carnegie Tech management game.[2] In general it would seem to be more likely that the proper blend of structure and behavior will be achieved.

Conclusions

The approach to system characterization described here is intended to provide a balanced perspective in two ways. For one, behavioral and structural properties are combined in a manner which affords a means of attaining the proper balance of these properties in whatever study or investigation is contemplated. For the second, since the same characterization serves as a point of departure for studies ranging from inquiries into system procedures to mathematical programming investigations of response times and response reliabilities to system simulations, there is a greater assurance that these diverse efforts will complement each other effectively. Alternatively, it should provide the basis for efficiently utilizing and directing the necessarily expensive activity of system simulation.

References

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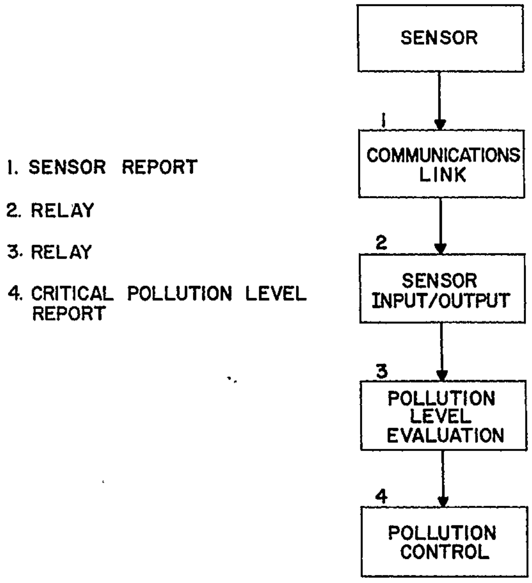

Figure 1. Typical Action Path: Pollution Control System