Problems in the Application of Systems Simulation to...

PN-ABI-401
72257
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380.5 Harvard Univ. NTIS
R646 Problems in the Application of Systems
Simulation to Transport Planning. Paul O.
Roberts and Donald N. Dewees. Sep. 1968.
30 p.
Discussion Paper no. 60.
Contract AID/csd-1543.
Proj. 931-17-995-476.

1. Transportation planning. 2. Simulation methods.
3. Models - Transportation. I. Title. II. Contract.
III. Roberts, Paul O. IV. Dewees, Donald N.

PROBLEMS IN THE APPLICATION OF SYSTEMS SIMULATION TO TRANSPORT PLANNING

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Discussion Paper No. 60

Harvard University

May 1, 1968

For Presentation at the Transport Research Forum

Kansas City, Missouri

September, 1968

PROBLEMS IN THE APPLICATION OF SYSTEMS SIMULATION TO TRANSPORT PLANNING

I. THE NEED FOR SIMULATION IN TRANSPORT PLANNING

A. Transport System Planning for Development
B. Simulation Models Described
C. Comparative Evaluation of Public Objectives

II. SIMULATION AS A PLANNING TOOL

A. Defining the System to be Modelled
B. Identifying the Point of View and Control Variables
C. The Role of Objectives
D. Model Building - The Design of an Information Machine

III. PROBLEMS IN THE USE OF SIMULATION

A. Data Collection and Use
B. Proving Model Credibility
C. The Computer Environment
D. Evaluating and Explaining the Results

IV. PRACTICAL USEFULNESS OF SIMULATION MODELS

A. Long Range Planning and the Role of the Model
B. Application at the Project Level
C. Transfer of Capabilities to Potential Users
D. Study in Team Effort
E. Costs and Benefits

PROBLEMS IN THE APPLICATION OF SYSTEMS SIMULATION TO TRANSPORT PLANNING

INTRODUCTION

Over the past few years the use of simulation as a tool of analysis has increased many-fold. More important, however, is the promise that this is a method of analysis with which many of the large complex systems problems facing us may be attacked. Though simulation is more properly referred to as a method of approach than as a general purpose analytical technique, it does appear to offer a framework conducive to understanding these problems and seeking rational methods of improvement or solution.

The authors have been engaged during the past three years in the application of simulation to the problem of transportation and its role in economic development.[1] This has involved the development of large system simulation models of the economy of a developing country and its transport system. The models, originally designed as research prototypes have subsequently been converted to planning models and used in a study of investment priorities in the transport sector of an actual underdeveloped economy.[2] The results have been gratifying. The experience in model building, calibration, data collection and operational use which resulted has been illuminating, and has attracted widespread interest.

This paper is an attempt to generalize the results of this experience to the larger questions posed by almost any use of

simulation for large-scale systems problems and particularly those involving transportation. The author's experience in the application of simulation to problems in transportation analysis includes a number of previous smaller scale models in various contexts, and these have also exerted their influence on the material presented here. The result is a set of rather general comments on a number of the more important aspects of the application of simulation to problems in transportation planning and analysis. The emphasis, however, is particularly on the application of simulation to large-scale systems for planning purposes.

I. THE NEED FOR SIMULATION IN TRANSPORT PLANNING

A. Transport System Planning for Development

Transportation planning has at times been viewed as a simple process of determining where the greatest need for increased capacity or improved travel conditions exist and then staging an investment scheme for these areas. It must by now be clear, however, that transport investment does much more than simply relieve congestion or lower operating costs. The consequences of transport policies which result with or without comprehensive planning reach far beyond the transport network itself, because transportation system planning can strongly influence the spatial aspects of development. The locational allocation of investment funds alone can be an important force

in channeling growth. Transport cost differentials created by new facilities tend to reinforce the emergent investment-induced growth patterns and to result in economies of scale in production and marketing as growth continues. Thus, transport planning may be used as a device for directing development when it is not simply a direct response to an existing or potential need.

The governmental role in transport planning has long been firmly established by the necessary involvement of governments in transport development and operation. Many transportation facilities such as roads, airports and ports are constructed with public funds, so their construction and operation must be planned publicly. Furthermore, the nature and behavior of the transport industry has created in many countries a need for substantial governmental regulation of pricing and other aspects of the private sector of the industry. Thus governmental transport system planning involves selection of projects for new construction, design of an integrated network of improvements or to the existing system, and development of satisfactory regulatory and pricing policies.

The purposes to which this control over investment and operation will be put, however, are neither clear nor easily defined. Multiple and conflicting objectives are the rule rather than the exception when the system is viewed from the level of government. It may even become more, rather than less,

difficult to find clearly preferred solutions at the governmental level since the number of viewpoints which must typically be considered is greater when government rather than an individual looks at the problem despite the fact that the conflicts are there internalized.

Though government control is evident in many aspects of transportation investment, there is also much freedom of choice in the balance of the industry. Shippers are free to make their own selection of mode and routing. The market process, though affected by the transport network that is available, is in most countries free to respond to the price system. Private investment is not particularly constrained by government transport policy. The response of the private sector to the implementation of a particular set of government policies might be thought of as the behavioral response of the system under study to external stimuli.

The size and complexity of the transport network in most developed countries defies thorough analysis by the most advanced techniques. The systems must be partitioned and dealt with in an incomplete way for the most part, although it is recognized that such project analysis is not entirely satisfactory because it omits the systems effects which are so important in transportation generally. In many developing countries, however, the transport networks are less complex and the economies

are simpler and thus easier to deal with. In such cases, the construction and use of simulation models of the economy and the transport system is entirely practicable as a method of exploring the consequences of alternative courses of action.[3] As simulation techniques become more efficient and flexible, they will undoubtedly be more widely applied in advanced countries for regional transport planning, urban growth and similar studies.

B. Simulation Models Described

Clearly transport planners need some technique which will enable them to evaluate various alternative transport plans and projects. Traditional analytical tools have proven satisfactory for project analysis where some simple objective function is to be optimized, but where a large system must be evaluated, with numerous discrete functions and scattered exogenous specifications, such analysis becomes less effective. Where no single objective function can be decided upon or clearly defined, it is necessary to try to reproduce the important consequences of a given plan so that its impact on the various affected parties may be determined. This requires a simulation model.

A simulation model is an abstraction or conceptual construct of a system which attempts to replicate the relevant behavioral responses of the system to changes in its environment, its structure, or its operating rules. The model can be manipulated to approximate the controls that exist in the real world and the

system response observed and evaluated. A simulation model may thus be useful for formulating alternative courses of action. It is,however, no different from any other kind of mathematical model, although it is used in a slightly different way. It is used primarily to create a history of the status of the many components of the simulated system at different points in time. During the calibration process, state histories of the simulation model thus created are compared with the state histories of the real world. To use these models for planning, alternative state histories of the future possible plans may be compared.

It is important to distinguish between a simulation model and an optimization model. Overall optimization of a particular function is not typically an objective of simulation models. They may, however, have subcomponents or subsystems which employ optimization techniques in the simulation of the behavioral response of that subsystem. Simulation models may be used to explore more than one objective or no objectives at all. Optimization models by their very nature must have one and only one objective and are thus not suitable for analysis of very complex problems where decisions must rest on a variety of factors including strong political forces.

C. Comparative Evaluation of Public Objectives

Since the problems that decision makers face in a public policy situation are not usually single dimensional problems

with a single objective, but rather have multiple objectives, simulation models are particularly appropriate tools for their analysis. The typical decision maker does not want to know which of the possible alternative courses of action facing him is the "best". He more frequently seeks the differences in consequence between these alternatives. For example, he might be interested in exploring the consequences of spending a large amount of money and creating substantial benefits or spending a smaller amount of money and creating a smaller sum of benefits: between payments by one group and payment by another, or between benefits to one or another. He may even be interested in what the beneficiary will do with the benefits which he obtains. A simulation model is ideal for tracing these types of benefits since it must establish their incidence prior to simulation of their behavioral response.

Simple project analysis procedures do not do this. They take a single government viewpoint through the use of a public welfare function. All benefits, though accruing to definite separate groups, are added together in a single welfare function, so the incidence of benefits is frequently lost. That such a process is inadequate to a real understanding of the consequences of a course of action may be illustrated by the following example. In the real world for every cost saving by one party the suppliers of the commodity which was saved lose a sale.

The important effect of this resource saving depends on whether the resources can be re-employed elsewhere in the economy. If they are truly scarce resources they usually can be re-employed. Their price will then drop until the market is cleared by sales to those who previously could not successfuly bid for these scarce resources. The price at which these commodities can be sold depends upon the elasticity of demand with respect to price, the market perfection and the degree to which profits are passed on in the form of higher income which tends to increase demand. Project analysis techniques are totally incapable of tracing the effects caused by these resource savings and their re-employment into the economy although these effects are vitally important to economic growth. With a simulation model the trade-offs can be established to show who has benefited, by how much, and at whose expense. From a political point of view, the distribution of benefits may be the most important aspect of a transport improvement.

II. SIMULATION AS A PLANNING TOOL

A. Defining the System to be Modeled

Simulation of the entire world in some detail is not practicable now, nor would it provide substantially more useful information in most cases than simulation of the small portion of the world that is of immediate interest. When one carves out of the world the small portion that is to be simulated, however,

one cannot forget that the rest of the world exists, but rather one must carefully define the boundary of the simulated part so that in all important respects the remainder seems still to be present, and the simulated portion is constrained at these boundaries to behavior consistent with the outside world. The outside world is thus represented by exogenously specified variables or by constants. It is advantageous to locate the boundary to minimize information transfer at the interface, so that data gathering and verifying is minimized.

These boundaries exist in time as well as space. A simulation run must somehow be started, so system status must be specified at the beginning of the initial time period, requiring far more data than the external constraints specified in later time periods. It is important to arrange logically what is in the system of interest and what is external to it, which variables are to be computed internally and which are to be supplied from the outside.

After determining the boundaries of the simulated system, it is then defined in detail with all of its subsystems and the appropriate interconnections. Each subsystem is analyzed physically and then structured logically in terms consistent with the model. The model may include operating rules, such as pricing policy or equipment scheduling as well as physical components, such as roadways or vehicles.

Once the important behavioral subcomponents are identified the information flows between these subcomponents must be rigorously defined. Cash flows and other informational and control data must be known in sufficient detail that the behavioral response of the subsystem can be accurately modeled.

Establishing carefully the level of abstraction which is appropriate to the policy questions at hand is very important, since working at a lower level of abstraction than necessary introduces a tremendous number of unimportant variables. It must be sufficiently concrete to provide accurate answers of the type desired, but not so specific that it exceeds the capability of available computers or data-gathering forces. Furthermore, the detail involved should be consistent in all parts, to avoid expensive generation of very detailed results in one part which are based on much less reliable results from some other part. Note, however, that the emphasis is on consistency, not uniformity. It may be both reasonable and useful to expand one section of an otherwise general model with great detail, so long as this expansion is designed to be accurate given the type of detail produced and used in the remainder of the model. For example, an economic and transport simulation can represent an economy as composed of ten industries, nine of which are defined quite simply, the last being transport which is simulated in very great detail, but appears, to the economic model, like any of the others.[4]

B. Identifying the Point of View and Control Variables

The model which is to be used as a pure simulator needs no particular point of view. However, if the model is to be used to study the relative merit of different policy alternatives then the planner's needs must be kept in mind and the point of view to be taken must be clearly established, with the inclusion of controllable variables to be manipulated by that particular actor. The identification of a point of view is also necessary for selecting outputs which will be related to potential objectives. Though these may be included at a later date it is always more difficult to modify the model once it is completely defined. Note that the variables selected by one particular agency as controllable may not appear controllable to another. The degree of control which will be exercised over these variables may not be known precisely, but this is not crucial for model design except that the model must be stable and accurate over the expected range of values. The degree of control exercised is really a problem of data gathering rather than programming, since control variables will always be supplied exogenously. In addition to controllable variables or policy variables, environmental variables representing the interface with the unsimulated world are also specified exogenously.

C. The Role of Objectives

With a simulation model, policy objectives need not be selected in detail because the model simply reacts to exogenous

inputs and explains what conditions will result. Potential objectives need be identified only to the extent necessary to define the output desired. Output will typically include variables which define the performance measures and summary statistics that will be used in evaluating alternative policies. Multiple, even conflicting objectives, may be applied by those who finally evaluate the results produced by the model. In fact, given adequate outputs from the model, the objective need not be selected until after several runs have been made and the results studied. One can learn about the behavior of the system from model runs and then formulate an objective function which is consistent with this new understanding, rather than being locked into an objective function conceived in the state of understanding which existed before the model was completed or run.

Models defined in this manner may be used to evaluate the degree to which the interests at different groups each with separate objectives are served because no objective function is implicit in the model, and no attempt is made within the model to resolve conflicting objectives. There may be, in fact, no way to resolve these external conflicts short of political activity. Toward that end, by organizing available data and adding to it, the model gives very complete information about the variety of conditions which will result from implementation of different plans, providing a time series of such information, so that the

tradeoffs between various groups over time may be traced in detail. This provision of a large volume of detailed results is perhaps the most important reason for the use of a simulation model for development planning.

D. Model Building--The Design of an Information Machine

A simulation model is usually structured one subsystem at a time. These subsystems are typically mathematical components held together by an information system and its computational sequence. For most transportation systems, it is difficult to characterize the entire system of interest in terms of a single mathematical technique. The model of a particular subsystem, however, may be quite pure in concept; for example it may be represented as a Markov process, a linear program, a stochastic birth and death process, or a problem in queuing theory; and as such may be symbolized using the mathematics usually employed.

For example, separate submodels may be used to represent road, railroad, river, and port operations within a single transport system simulation. The port simulation could be represented by a simple queuing model, while the road simulation might consist of numerous functions relating congestion, vehicle shortages, operating characteristics. Each of these subsystems must be provided with the data necessary for its operation, and return to the main program the requisite informa-

tion describing the performance of that mode.

Some mathematical programs involve massive computations but little information transfer because they are an iterative process on a small amount of data. The simution of a large real world system such as a transportation network, however, must necessitate manipulation and storage of a vast body of data describing the state of the many parts of the network. If the data requirement of the simulation program exceed the primary storage capacity of the computer to be used, special routinswill be necessary to move data to secondary storage when it is not in immediate use. In the case of the large scale simulation performed by the authors the program and data exceeded available core storage in an IBM 7094 by a factor of five or more, requiring a complex overlay structure using up to 18 tape drives. The low speed of secondary storage access time demands that such storage usage be designed very carefully to avoid great inefficiency in running. Great sophistication in information handling, however, makes a program much harder to work with, alter and debug, so it is necessary to carefully balance the competing needs of efficiency and simplicity.

For most computing equipment operations must be structured so that they can be performed sequentially. Most economic processes and many parts of the transportation system require equilibrium conditions which imply simultaneous determination of the states of all variables. Since computers must operate sequen-

tially, simultaneity is ordinarily achieved by means of iterative procedures or by the use of recursive processes which, though always slightly out of equilibrium, may be sufficiently close for practical purposes. Modal choice and routing are transportation processes which are typically thought of as equilibrium seeking, because traffic volumes are a function of performance and performance is likewise a function of traffic volumes. Simultaneous solution is thus required.

Since iteration demands a great deal of time, recursive procedures can frequently be adopted in which the state of the variable from the last time period is used as an estimate of its state in the current time period. This technique will generally be found satisfactory where the response time of the system is long relative to the computation interval and/or where system performance is not a function of rapidly changing variables.

III. PROBLEMS IN THE USE OF SIMULATION

A. Data Collection and Use

The data needed to support a simulation model is typically of two types. First, there is the data needed for exogenous input ad environment or control variables, and second there is the data needed for calibration of the behavioral parameters.

Environomental variables are obtained by observing the system in its natural setting. Control variables are somewhat more complex in definition since they represent the mechanism by which the system as a whole will be managed. Data containing information about the way the system has worked in the past is used to estimate the behavioral parameters. Most simulation models demand consistency in behavioral data because of the systems nature of the process. Output from one subsystem is input to another so that data errors are multiplied. Errors in one subsystem will ultimately be evident in a study of the overall results. In view of the fact that the data for a real world system is typically less complete than is desirable, this consistency check performs valuable function of bridging data vacuums.

Collection of the data always poses a problem, from which simulation models offer no particular relief. However, with a full feedback model the system can frequently be defined in such a way that data collection is minimized. By using a model of the entire economy and the transport system, for example, one avoids the necessity of collecting origin

and destination data to generate traffic flows. Thus, data which would have been entered into the system exogenously under one definition of system boundaries becomes data which is used to calibrate the parameters under a broader definition of system boundaries. Parameters, however, can frequently be calibrated with incomplete data since the redundancy in most systems provides more data than is necessary to establish these parameters.

When the model is operational, sensitivity tests can be made to determine which variables and parameters have the greatest impact on the results and which have little impact. Armed with this knowledge, the user can concentrate his energies on providing accurate data for the more sensitive areas and invest less effort in collecting the less crucial data, thus minimizing the data collection effort employed. It should be understood that even when a model is carefully designed to use published or existing data, it is usually not possible to prepare data for use without a thorough understanding of how the model works. The model is an abstraction from reality, and as such will almost always require that data be adjusted in some way to remove errors or inconsistencies. The unfortunate truth is that most data are not simply numbers, but require a precise definition of the quantity they represent. As this verbal definition varies from one source to another or one time to another, the numbers must be adjusted to fit the definition implicit in the model.

One of the virtues of a simulation model is that the internal information storage and retrieval system becomes a useful device for organizing the various data in a standard and easily understandable form. As such it often affords a convenient device with which to coordinate the work of various individuals. As they provide data or evaluate model results, the expert opinions of consultants can be entered into the process. The model and its data bank thus become a storage for the wisdom and knowledge of those who have contributed to its development. This storage is superior to a stack of published reports, in that every use of the model automatically relies upon that data, while a report may be ignored or forgotten when new decisions are to be made. As additional data is collected, it can be used to enrich the data bank which already exists. Data errors can gradually be identified and eliminated. The models can therefore serve as a device for data enrichment and improvement, as well as storage and retrieval.

B. Proving Model Credibility

A simulation model is useful when it behaves and responds as the real world does with respect to the variable and functions of interest to the user. Therefore, before using such a model such as model as a planning tool, one must be convinced that in fact it is accurate where desired. This comparison should include both a steady state analysis and evaluation of

transient response to disturbances of types which may occur in projected runs. Data from an historical period will usually include typical disturbances and the response to them which is expected in the model. Calibration is achieved by adjusting behavioral parameters in the model until the state histories of both the real world and the model compare favorably. Behavioral parameters can be established by regression where sufficient data is available or by an informed estimate where it is not. The final test, however, is the way in which the parameter setting influences the behavior of the subsystem as it is sequenced through actual state histories. It is true that in a case where there are many parameters for which calibration data is not available, there may be several different ways to arrive at apparently similar state histories. Sensitivity analysis of the model can usually reveal this situation after which a more specific data collection effort may be required. Where there is more than enough data, however, there will be degrees of freedom which will not be completely utilized and these can be used to furnish a check on the consistency and the calibration of the model.

Model credibility can never be established perfectly. One must in the final analysis use his own judgment and experience in declaring that a simulation model is sufficiently realistic to be used for policy problems. And if consistency errors are suspected which render a single run unrealistic in

some respect, the model may still be useful for producing sets of runs in which differences may be compared because the errors cancel out.

C. The Computer Environment

Most large scale simulations involving transportation system and economic development models require high speed computational equipment with large memory because of the complexity of the programs and their development. Present machine sizes require that the programs will have to be divided into several parts, any one of which may tax the capability of the machine. Working close to the limits of the available technology demand that both programming and hardware systems must be well developed, free of problems and completely understood. The programming languages used must be completely debugged if serious delays are to be avoided. General purpose but universal programming languages should be used if they can because of the ease of documentation and translation to other users. Systems programmers with an expert understanding of the language used must be on hand. For development, programs should be subdivided so that they can be tested separately, then put together piece by piece and debugged as increasingly larger subsystems. Calibration can proceed simultaneously as soon as major debugging has been completed. Data must also be debugged, since completely error free data is rare.

Development of simulation models requires a computer budget

that is somewhat larger than that for many other types of computer uses. Because this path is new and relatively untravelled, there are typically many false starts. The physical volume of data in and out, as well as the desire for fast turnaround suggest that it is highly desirable to have an office close to the computer where data can be organized for input and where runs can be analyzed after they have been returned. The extremely high speed of an electronic computer and the nature of the simulation process mean that a very large amount of output can be generated. To conserve analysis time, output data should contain both details and summaries ranging from the most aggregate measures to the more minute. It is also useful as well as conservative of paper and carrying energy to have the ability to suppress the printing of any of these at will.

D. Evaluating and Explaining the Results

The output obtained from a simulation model can be quite voluminous because it contains detailed descriptions of the state of a complex system at many points in time. Therefore, a great deal of thought and experimentation with the results is necessary to see what is significant, which output is most responsive to change and which are the best indicators of important activity. It is helpful if a hierarchical system of output presentation can be evolved with higher level summary

results presented initially and with more and more detailed results available on demand. Computer-drawn maps, charts and graphs are an excellent form in which to present output summaries for quick comprehension. If results are to be shown to a client, it is invaluable to present them in a format with which he is familiar to speed recognition and understanding.

Output design is greatly aided by an understanding of how the results will be used. Runs will ordinarily be compared in pairs, one run will incorporate some design feature under study; the other run omitting it. The results will then be compared item by item between the two runs. It will also be important to generate results so that the entire sequence of a particular economic or transport indicator can be viewed as an individual time series. Time series of interest may include regional economic indicators, modal measures of various kinds, or overall transport system performance measures.

IV PRACTICAL USEFULNESS OF THE MODEL

A. Long Range Planning and the Role of the Model

Within many planning agencies there is a tendency to focus on short range as opposed to long range planning functions. One important role for simulation models in a planning context may therefore be to organize and focus the central planning function on long range objectives. This should not be done statically, by focusing on a single point in the future, but rather dynamically

by focusing on the changes required to accomplish desired objectives over the years.

Planners can typically select from alternative plans several which are desirable, practicable, and achievable in the time period under consideration. Using simulation, these alternatives may be tested and the results analyzed to determine which is most satisfactory from a number of viewpoints including the view held by those responsible for making the final decision. Presumably, steps will then be taken to implement the preferred plan. After a time has passed, however, external events may occur, changing assumptions on which the plan was made, foreclosing some alternatives and presenting new ones. It will then be desirable to make a new assessment of the present, new projections into the future, and simulate again to find a revised "best" plan. Thus, the planning and modelling process is dynamic and iterative, absorbing changing external conditions and adopting them. Simulation techniques when used in such a dynamic planning process makes it possible to identify easily those projects or programs in which early starts are essential to completing the overall program and to achieving the benefits expected out of their completion.

B. Application at the Project Level

Simulation models can be applied at the level of individual projects but this is expensive and not well adapted to examining the details inherent in project analysis. It is easy enough con-

ceptually to hold constant all program planning except the project of interest; then simulate it in several different forms. Depending upon the overall system model, these changes in form may allow the exploration of all the detail desired. More frequently, however, the differences between the projects may be minute compared to the scope of the systems model so that adequate answers cannot be provided project by project because the resolution of the model is not sufficiently fine.

There are theoretical problems with priority ranking of projects in the first place. It is difficult, if not impossible, to place a priority rank on an individual project since it is only one element in an entire program of investments. As the background program is changed, the usefulness of the project and therefore its priority ranking, may change because of its relationship to the background system. Project analysis, as it is presently practiced, attempts to select that project which has the highest individual objective ranking at a particular project site. Priority ranking then attempts to place these individual projects into an overall program while assuming total independence between projects. Most transportation projects, however, are not independent of the remainder of the system, and their importance or priority will depend heavily on other aspects of the transport development. The amount of interdependence may vary from system to system and must be considered independently for each different application.

This does not resolve the problem which faces the typical network designer. There are literally thousands of permutations and combinations of projects that may be conceived of. A simulation model is not a useful technique for selecting among these since it does not exercise choice among the available projects nor does it suggest which combinations are better. Search techniques such as mathematical and dynamic programming may be useful in this regard. It is the opinion of the authors, however, that the range of feasible choices is well constained in many transportation systems and the decision maker has a number of political constraints on them which limit the range of choice to a few discrete possibilities. Where this is the case, simulation can be useful for selecting among these choices.

C. Transfer of Capability to Potential Users

If simulation models are to be important for policy making in the future, it will be necessary to surmount the problem of transferring the technology which has been developed in various research laboratories into operational techniques in the individual agencies. This is first and foremost a job in education. The operating agencies must have techniques and professionals who understand simulation modeling and its uses in transportation planning. In many countries there are undoubtedly shortages of trained manpower with satisfactory technical background and college level training to handle simulations. This is not universally

true, however, an in many countries the reverse situation exists. If a small percentage of the population of a developing nation are sent to good schools at home and abroad, their technical education may actually be greater than can be effectively used within the country. If opportunities to exercise this training that they have received are not made available then these people can be lost through a "brain drain." Thus a domestic simulation program might not only be productive, but can attract the best technicians to remain in their country.

Another possible barrier to use of simulation models by developing countries is the inadequacy of their computers. A few developing countries have satisfactory computational equipment available. Most, however, must depend on equipment in the developed world. It is possible, though relatively difficult to perform the model building and data collection tasks at home while using a computer located in some other country. This, of course, flies in the face of our earlier advice to locate near the computer, but may in some cases be necessary. Once models are set up and operating, the analysis team could fly into a computer center to use them for individual runs, although this would not usually be satisfactory for intensive use of the model.

D. Using the Model: A Study in Team Effort

For large scale simulations, the development must be a group effort until the entire simulation is operational. No one in-

dividual in the group can operate all alone except during those periods when he is working on the internal aspects of an individual submodel. Even then the interdependent nature of the system will force the group to come to grips with the information transfer between subsystems and the dependent nature of each subsystem on the operation of other subsystems.

Because such great individual familiarity with the particular model is required to use it, the life of the model is essentially the life of the group. Any one individual can be lost without severe repercussions to the overall endeavor. But if several are lost at the same time, then the effort must be begun again.

In addition to the purely systems aspects, such as information transfer and computational procedure, there are any number of small reasons why the group must function as a single unit. For example, locating the information used as input to a particular subroutine will typically require that specialized knowledge held by one member of the team be transferred to another. The data sought may be in a particular room, punched into cards and stored on a shelf with a number of other cards of the same general type and readily identifiable only by the fact that it is punched on red cards and has a blue rubber band around it. Thus the same information storage and retrieval process that is vexing in the internal design of the model may turn out to be equally difficult in the real world. The design of information files and the education of the entire group in their use can be essential. Smoothly working operations must also be evolved

such as check lists, methods of labelling output, systems of names for various types of operations, etc.

Working with a simulation model is a complex undertaking. It is not quite the same as dealing with most machines since with most the state of the machine is more or less obvious to the observer. In a simulation model the overall structure can be concealed in vast quantities of data and the operation completely hidden inside the computer. It is quite difficult to get an adequate appreciation because there is no vantage point from which an overview can be obtained. Careful attention to detail and a willingness to work together on the part of the development team is essential to success.

E. Costs and Benefits

Performance of a large scale system simulation will require a staff including several engineers, economists and other professionals. Organizing and staffing a study team and allowing it to function freely costs money. There will be an educational period during which no answers will be forthcoming before models can be constructed. The trail can be long and tedious but it is potentially rewarding.

In general the group should be established to function in a consulting or staff role relative to the decision maker with the responsibility for the major policy decisions for which the

models are being constructed, such as the president, a cabinet level minister, the mayor, the head of the planning department, etc. The models will in many instances serve as pedagogical tools for staff training. Its importance in this role should not be underestimated. Once the models are functioning well, they can be used to test alternatives as they are proposed. The importance of new projects to overall programs can be evaluated and they can be placed in time-staged programs. As more accurate cost and design data is available for individual projects, they can be retested to insure that the importance of these particular projects in the overall program has been maintained.

Decisions arrived at by working with the model will almost never be taken solely from the numbers produced by a particular simulation, but rather from a broader understanding of the relationship of the response of the system to various actions obtained by working with the model. Perhaps most important, a simulation model is simpler in concept than a typical project analysis. The consultants are informing the decision maker not about some mystical measure of quality proposed by a public welfare function but in terms of consequences he can more readily understand.

While it appears that the cost of developing and maintaining a simulation model and capability will often be substantial, this should not discourage potential users. Very large amounts of money may be invested in transportation facilities, so a small

improvement in the efficiency of this investment would support a rather large planning activity. Such a model allows planners to test numerous alternatives and observe the consequences of their adoption in a degree of detail achievable in no other way, and this ability alone would probably lead to more rational and efficient decision-making, whether specific results were specifically applied or not. And to the extent that the economic aspects of such a model could be used in non-transport studies, the benefits can be much greater than if only a single purpose is pursued. Finally, the rationalization and enrichment of all data used in the model, economic as well as transport, may encourage better planning in government departments seemingly remote from transport planning.

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