COMMUNICATION NEEDS IN COMPUTER MODELING

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ABSTRACT

With the development of computer-based group communication media, the computer may play an increasing role in managing the complexities of the modeling process. Large-scale policy models are usually developed by groups of five to seven people. Frequently, some of these model builders work in different locations around the country; they nearly always come from at least two or three different disciplinary backgrounds. The users of their models typically come from different organizations, with their own perspective on problem solving. These basic characteristics of the modeling environment create a number of communication problems. These include communication barriers between model builders and users; obstacles to communication among model builders; inadequate documentation; and problems of validation. To address some of these problems, communication-oriented computer software should provide more frequent communication in the modeling group, easier record-keeping, special formats for presentation of results, structured interaction, and user training procedures. This paper examines the communication needs in modeling and introduces a computer-based communication system designed to meet some of these needs.

INTRODUCTION

A model is an organized set of interrelated assumptions about a system or process. It may be used to understand the structure and operation of a system, to study the behavior of a system under a variety of conditions, or to forecast future outcomes. For any of these purposes, a model is basically an integrative tool for coping with complexity--stemming either from a large number of variables or from the nature of interconnections among variables.

With the introduction of computers, the ability to model very complex systems or processes increased dramatically. In particular, it appeared that complex social systems might be better understood using computer-based mathematical models. Accordingly, policymakers in city, state, and federal governments as well as in private corporations have often made considerable investments of staff and money in the development of large-scale computer models as decision-making aids.

However, both modelers and users of models acknowledge that such models have not been used successfully in making policy decisions. And with this growing awareness of model deficiencies, several studies have attempted to evaluate the process of constructing and using computer models, looking for clues to their future improvement.

Parallel to the growing recognition of problems with computer models has been an increased interest in the potential of computers for noncomputational applications. Specifically, several computer programs have been developed to support human communication through a computer network. These include computer conferencing systems. The features of such systems could, in principle, be applied to various stages of the modeling process. The important questions for the modeling community are these: What communication needs exist in the modeling process? And how might computer-based communication systems be best designed to meet these needs?

Our purpose in this paper is to survey the existing evaluations of modeling efforts and summarize their major deficiencies. From these deficiencies, we then identify communication needs that might be met by computer-based communication systems. Finally, we outline one approach to using the communication capabilities of the computer to meet some of these communication needs.

FIRST, A WORD ABOUT THE MODELING PROCESS . . .

Descriptions of the modeling process typically include a series of stages, such as the following:

Stage 1: Definition of problem issues and objectives

Stage 2: Development of problem solution plan

Stage 3: Formulation of mathematical model

Stage 4: Analysis of data requirements and availability

Stage 5: Collection of data

Stage 6: Construction of computer programs

Stage 7: Debugging and verification of programs

Stage 8: Determination of computer run to be executed

Stage 9: Execution of program and analysis of results

Stage 10: Validation of the model

Stage 11: Presentation of results to users

Stage 12: Model use and maintenance procedures

In reality, of course, virtually no one constructs models by the mechanical application of each of these steps. For example, the process typically resembles a series of loops, in which the modeler repeats three or four stages several times in succession. Also, some of the stages may receive considerably more attention than others. Furthermore, this 12-stage scheme does not acknowledge many of the peripheral factors that influence the modeling process--such as individual workstyles, organizational boundaries, and time and budgetary constraints. Such factors are inseparable from any specific modeling process and may contribute appreciably to many of the deficiencies in modeling.

Nevertheless, the modeling stages listed above are useful for defining the range of activities that typically occur in modeling efforts. And it is clear from this range that at least half of the activities--particularly those at the beginning and end of the process--are heavily dependent on the capability for effective communication. It is thus not surprising to find that many of the evaluations of the modeling process point to communication as a major deficiency.

THE DEFICIENCIES: A SUMMARY OF EVALUATIONS TO DATE

In the past 15 years, a number of investigators have attempted to evaluate the modeling process. One of the earliest of these was Cline's 1961 survey of over 50 weapon system models [4]. Among the more recent efforts are evaluations of environmental, urban, agricultural, energy, weapon systems, and corporate models. They include models developed for both defense and nondefense agencies for both the public and private sectors.

Before describing the results of these evaluations, it may be useful to summarize the methodologies employed. Perhaps most monumental was a questionnaire survey by Naylor and Shauland [23]. In an effort to summarize the corporate experience with models, they sent questionnaires to 1,880 corporations and received 346 responses. Fromm, Hamilton, and Hamilton [9] developed two separate questionnaires for directors of federally funded projects and project monitors from the respective federal agencies; this project produced 316 responses. Shubik and Brewer [25], working with the GAO, used questionnaires to survey 132 users, builders, funders, and caretakers of simulations, models and games for the Department of Defense. In another study, the GAO [13] sent questionnaires to 538 federal, state, and local agencies that developed and/or used computer-based models. Finally, researchers at the Holcomb Research Institute (HRI) [15] interviewed more than 100 individuals concerned with environmental modeling.

Several investigators have also relied on workshops and conferences to uncover some of the problems in the modeling process. Holling and Chambers [16] conducted three workshops to examine the process of interdisciplinary problem-solving. Amara [2] convened 14 model builders to examine the social implications of computer modeling and simulation. In 1974, Mar [19] developed an experimental process to stimulate discussion of the modeling process in small groups of peers; in 1977, he conducted workshops with participants in 18 projects from the Regional Environmental Systems program of NSF/RANN [20]. Kuh [18] organized a conference of nearly 50 model builders to discuss model formulation, validation, and improvement as well as the specific problems of modeling large-scale systems.

In addition to these broad surveys, there have been a few case studies, such as Mar's [21] analysis of the 18 Regional Environmental Systems projects; a GAO [12] evaluation of the Transfer Income Model to analyze welfare programs; a review of the work at Oak Ridge National Laboratory for the Regional Environmental Systems Program by Craven, Olsen, Reichle, Schuller, and Voelker [6]; and case studies of four energy policy models by Weyant [26]. Gass [11] surveyed a range of studies and proposals on model documentation to uncover problems and potential solutions. Abel, Folstein, and Bowling [1] outlined the limitations of models for policy analysis based on their experience with the Department of Energy. Finally, Brewer and Hall [3] "evaluated the evaluators" of Forrester's *Urban Dynamics* effort to suggest the outstanding needs of large-scale modeling.

All of these efforts recognize deficiencies in the modeling process which, in turn, lead to problems in their effective application to policy decisions. These deficiencies point to four major problem areas in which communication is a key issue. These may be summarized as follows:

PROBLEM AREA 1: COMMUNICATION BETWEEN MODEL BUILDERS AND MODEL USERS

The use of large-scale models as decision-making aids introduces an immediate and explicit communication problem. Often, the users of such models do not themselves have the skills to construct a model; hence, the building and use of a model become two distinct segments of the modeling process, with different people involved in each stage. This segmentation of the process means that some formal communication structures must be established between the builder and user. Otherwise, the models simply are not used. But it appears that neither the model results nor the skills for using the model are easily transferred. Shubik and Brewer, for example, report that in 11 percent of the cases they studied, no briefing occurred at all, and 42 percent of those surveyed did not know whether a briefing had occurred [25]. Model builders seem to find it difficult to present results to users; they prefer to focus on the modeling issues [19]. And even when the results can be transferred, the users may not fully understand what they are getting. Users often will not know how the model works or what assumptions are built into it. This lack of understanding can mean, on one hand, that model users will place too much faith in the model results or, on the other, that they may be reluctant to use the model at all.

Mar points out that transfer of the model must be an iterative process involving the gradual acceptance of: (1) the philosophy and methodology of the effort, (2) the technology and actual software, and (3) the results of the model [20]. Unfortunately, there are organizational and perceptual barriers to such a process in addition to the technical barriers.

ORGANIZATIONAL BARRIERS

Communication between builders and users is often limited by geographical distance as well as institutional barriers. Fromm [9], for example, claims that model use is a function of the "distance" to the developer, as do Abel [1] and Weyant [26]. Also, users may have limited resources--time, money, and personnel--for interacting with model builders [15]. Furthermore, there are no obvious rewards to improve interaction. Even if contact is developed and maintained during the model construction, personnel shifts in the user agency often signal the end of the model's useful life [20, 24].

More subtle barriers are raised by institutional politics. Mar suggests that physical models may be more transferable than social models because "site-specific" social issues are frequently built into the latter [20]. That is, the definition of the modeling problem may reflect the specific mission of the funding agent. Also, organizations often have their own sources of information and analytical frameworks that may compete with the model for authority in the decision-making process. In fact, Weyant suggests that a reliance on in-house modeling staff--rather than external contractors--increases the likelihood that a model will have an impact on policy decisions [26]. He further suggests that models fare better if the model builder holds a relatively high position in the organization. Unfortunately, top management is frequently not involved in the development and planning of a model; thus, key decision-makers may resist the use of model results, feeling that they do not reflect their needs [13, 20, 23].

PERCEPTUAL BARRIERS

Builders and users of models work in two different worlds, and each has its own worldview. The world of the builder is theoretical; that of the user qua policymaker is pragmatic, with political pressures to which the user must respond. Sheridan characterizes the difference in perspectives as follows: decision-makers are intelligent skeptics, unimpressed by the inner workings of the model or sophisticated techniques used to construct it; they are interested in the model "only to the extent that it can quickly and efficiently provide correct analytical information" [24]. Model builders, on the other hand, enjoy model building and value the sophisticated techniques they have acquired throughout their career. Given this difference, it is not surprising to see criticisms such as the following:

> Social scientists have been, by and large, dedicated to rigorous measurement and theory building, a dedication that has often produced results that are not terribly relevant for other orientations, intentions, and applications. [3]

Model builders are understandably more interested in the construction than the utilization of models [19]. Accordingly, they tend to feel that, if the model itself is relevant and useful, it will be used, regardless of whether it is well documented or *easily* used [14]. In the extreme, however, modelers may assume an entrepreneurial approach that focuses on selling a computer model without regard to the political context of the user's problem [3].

At the same time, model users perhaps expect too much of the modeling process. Policymakers, according to Brewer and Hall, seldom formulate their practical problems in terms that are sufficiently precise to permit the researcher to design an appropriate investigation. They may even rely on the model to identify central policy questions on their own [3]. Thus, "an essential part of the modeling process is the translation of policymaker's perceived concerns into researchable questions" [14]. Builders and users alike must invest more effort in determining the users' needs.

SKILL BARRIERS

In addition to organizational and perceptual barriers, the transfer of models from builder to user may be blocked by a lack of skills. Models that require radically new skills of existing analysts in the user organization are not as readily accepted as those which do not [19]. Also, verbal and graphical representations of models seem to facilitate the communication of model results better than computer-based materials, which may require new skills [19]. It seems particularly important that the user be able to understand and agree with the assumptions and limitations that are embedded in the model, but such an understanding may require a detailed examination of all of the algorithms used in the model--an examination that would require a considerable investment of time by the user. Skill requirements also have cost implications for the user: What will it cost to train people to operate and use the model?

HARDWARE BARRIERS

Finally, there are some hardware problems in transferring models from builders to users. Some large models contain computer-specific characteristics that impede transfer. And this problem could be exaggerated by the growing use of mini/microcomputers since software compatibility between these computers may be limited [20]. Thus, the promise of increased access through the introduction of minicomputers must be weighed against the potential for increased difficulties in transferring the model.

PROBLEM AREA 2: COMMUNICATION AMONG MODEL BUILDERS

Some of the most vocal critics of large-scale models are model builders themselves. Presumably, dialogue among the modelers would lead to faster construction of more credible models. Yet, many of the complaints about the modeling process concern communication among model builders. They include concerns about the failure of new modeling efforts to build on previous efforts; difficulties that stem from differing disciplinary perspectives; and tensions about the role of the individual in the modeling team.

FAILURE TO BUILD ON PREVIOUS EFFORTS

Nearly all of the evaluators of modeling mention the inadequate information flow between similar modeling efforts, the duplication of efforts, and the failure to learn from previous mistakes. Only a few offer any explanation, however. Mar [19] points out that the scientific and professional literature of modelers does not encourage dialogue on modeling issues; rather, the emphasis in this literature is on model results. He also suggests that there is no adequate system for recording the modeling process--a problem that is part of the larger issue of documentation. The resulting lack of confidence in existing models limits their use, according to Abel et al.; in fact, the effort to gain confidence may exceed that required to develop a new model.

DIFFERENCES IN DISCIPLINARY PERSPECTIVES

Large-scale models for decision making create a dilemma for the modeling process. On one hand, there is a distinct need for interdisciplinary collaboration in such efforts [18]. Without it, modelers may find themselves forced to develop theory independently and in haste [15]; also, modelers who are unfamiliar with a relevant discipline may not abstract the information properly in constructing the model [19]. At the same time, the research approach and even the working language varies across disciplines [19]. As a result, representatives of different disciplines will frequently fail to agree on the process for "decomposing" the system to be modeled into its constituent parts [15]. They may, in fact, disagree about what questions ought to be addressed and how they ought to be presented. Also, different disciplines have varying theoretical capabilities [15]. Mar [19] concludes that two or three disciplines are the maximum for an interdisciplinary project.

THE INDIVIDUAL VS. THE GROUP

Finally, while most modeling teams consist of five to seven people and while most critics feel that modelers would benefit from collaboration with others outside the project, many modelers view modeling as an individual process, which requires the "persistent commitment only an individual can develop" [16]. Thus, the tendency for people to "do their own thing" is recognized as one of the major barriers to dialogue among model builders.

PROBLEM AREA 3: DOCUMENTATION

Some of the problems of communication between model builders and model users as well as among model builders can be traced to difficulties in documentation. The evaluations of the modeling process offer countless suggestions about what documentation should include. Generally, they fall into two categories: explanation of the conceptual framework, assumptions, and limitations of the model; and basic information on computer programs and operating instructions [15]. But modelers or critics of modeling have seldom been able to suggest remedies for the major problems in documentation--namely, the lack of standards, the poor usability, and lack of motivation for modelers.

LACK OF STANDARDS

While there are numerous proposals for documentation standards and even a "mandatory" set of standards from the Department of Defense, no set of standards is widely accepted; as a result, the types of documents produced by modeling efforts vary from institution to institution [9, 11, 15]. A point often made is that there is actually no organized modeling profession that might provide any authoritative standards for documentation. Perhaps of more practical significance is the view that documentation is a "local" concern, subject to special local requirements *and* waivers of requirements [11]. Furthermore, Gass suggests that it is quite possible to conform to the standards without producing documentation that it is truly adequate for the needs of each major segment of a model's audience [11].

POOR USABILITY

Documentation is seldom presented in a form that is usable by intended model users or even other model builders. Most documentation is in the form of reports or articles rather than user manuals or program decks with commentary on the program [9]. The reports often exceed 1,000 pages [20]. Furthermore, the documentation is generally written in the language of the modeler's discipline--language that is obtuse for the policymaking user [19]. Finally, any existing documentation is usually available only from the model developer; no central clearinghouse exists [9]. Thus, even if the documentation is adequate for the intended user, other model builders and users may not be able to take advantage of it.

LACK OF MOTIVATION

Perhaps the most serious barrier to improved communication is the lack of incentives for modelers to document their efforts:

> Documentation is one of the most neglected aspects of modeling and simulation, partly because it is largely noncreative and therefore uninteresting. Furthermore, because it should be everyone's responsibility, it frequently becomes the responsibility of no one. (House and McLeod in [11])

Typically, users do not clarify documentation requirements, and builders complain that they have inadequate resources--time and money--for documentation [15]. But even more significant is the fact that there may actually be disincentives for documentation. If documentation is inadequate, the model builder retains ownership of the knowledge represented by the model; such ownership may be critical to the modeler's job security [15].

PROBLEM AREA 4: VALIDATION

The evaluators of the modeling process claim that, just as with documentation, model builders are not motivated to validate their models properly [13, 18]. And about half of all models are probably not subjected to review outside of the builders' or users' organizations [3]. The stumbling blocks here are fundamental. First, there is no agreement about the definition of validation; second, procedures for validating models are undefined.

NO UNIVERSAL DEFINITION

Everyone seems to agree that no one can agree about exactly what validation should be. The definitions range from "agreement between the model results and real-world data" to the "acceptance of results by users as a basis for decision making" [20]. In the middle are statements like: the model is valid when all of the important variables are included and none of the relationships between variables are incorrect by the modeler's standards [19].

Gass [10] has perhaps developed the most comprehensive definition of validation. He identifies three types of validity. First is *technical* validity. This includes the validity of the mathematical representations and causal assumptions of the model; the accuracy and impartiality of the data as well as the degree to which they are representative; the accuracy of the equations; and the predictive validity of the model (the correspondence between model predictions and historical data).

Second is the *operational* validity of the model. This may be assessed by evaluating the importance of errors or divergences between model predictions and historical data; by determining whether the model offers an improvement in cost savings over previous analytic tools; and by testing the model for "robustness"--that is, its tolerance for poor data. In addition, operational validity is defined in part by the way in which the model is implemented: Is it usable for its intended purpose?

Finally, Gass identifies the need for *dynamic* validity. To be dynamically valid, a model must include built-in procedures for maintaining and altering the model so that it will continue to be an adequate representation of the system being modeled, even after the system has changed.

In contrast to the extensive definition of validity offered by Gass, some critics argue against validation altogether: they claim that the concern about validation is "misleading to the extent that it diverts scarce attention away from the prior issues of intention, specification, and control" [3].

LACK OF VALIDATION PROCEDURES

Even if modelers could agree on a definition of validation--such as empirical cross-checking--methodological problems would remain as barriers to improved validation. Kuh, for example, cites the lack of methodology to validate large models for forecasting over a long period; since the future may be outside of the historical data range, traditional empirical validation seems most appropriate for small models or short-term forecasting [18]. He also points to the need for some way of measuring the goodness of fit of a system beyond equations.

Ultimately, validation is a measure of the confidence of a user in a model. In practice, confidence is established in three important ways: through a peer review that focuses on the "correct interpretation" of model results; through development of an understanding of the structure of the model and especially its internal consistency; and through recognition of the factors that are *not* considered in the model but are relevant to the policy decisions [1]. Both the definition and procedures of validation might best be addressed by systematizing these practices for establishing confidence in the model.

COMMUNICATION NEEDS AND COMPUTER CAPABILITIES

In each of these major problem areas of the modeling process, communication is either explicitly or implicitly at issue. To begin to understand how the communication capabilities of a computer could facilitate the modeling process, we might first consider the kinds of communication needs that are implied by the problems outlined above. These include the needs for more frequent communication, for record keeping, for special presentation formats, for structured interaction, and for user training.

MORE FREQUENT COMMUNICATION

First, there seems to be a need for more frequent communication between builders and users in a single modeling effort, as well as among modelers working on different projects. Greenberger, for example, is emphatic in stating that "the policy-maker's responsibility to the modeling project is to convey policy insights to the modelers by maintaining frequent two-way communication for the duration of the project" [14]. The Holcomb Research Institute reinforces this view when they point out that the model development should be an iterative process [15], and Mar concurs by saying that day-to-day contact is essential for best results [20]. He further suggests that one way to achieve user commitment to the model is to encourage user participation in development decisions. Users are also more likely to understand the model if they are introduced to it in stages rather than as a fait accompli, which may be difficult to understand in a single presentation at the conclusion of the project [20]. And if communication should be more frequent, it should also extend further at each end of the communication process: evaluators cite the need for more discussion of needs at the outset and for continuing user support once the model is operative.

One important advantage of more frequent communication is the "demystification" of the modeling process for model users. If users can observe the process in the early stages with all its problems and uncertainties, if they can participate in solving these problems, they should have a much better understanding of the model's limitations and proper users. While such an intimate working arrangement demands considerable trust and risk taking by model builders, their reward should be more user confidence in the final product.

The need for more frequent communication is clear. But geographical and institutional barriers raise questions about how to implement more frequent communication. Several suggestions have been proffered: the establishment of advisory boards on modeling projects; the use of conferences and workshops for builders and users to determine goals and preferences; the organization of workshops among modelers who are working in the same area; the requirement that modelers visit several existing projects at the beginning of their own work to identify commonalities; and the use of telecommunications and computer networks.

The computer does offer particular advantages for certain types of communication. Typically, computer communication systems, such as electronic mail or computer conferencing, are available 24 hours a day, providing long-distance communication that is not too expensive. In a computer conference, participants can enter at their own convenience, review the transcript of the conference, and add their comments for others to read at their convenience. Such a conference need not last only days or a couple of weeks; it can provide a continuous link between model builders and users throughout the model-building effort. An advisory board of other model builders might also be invited to "attend."

RECORD KEEPING

A second need is an efficient record keeping procedure that could help solve some of the problems of documentation. As noted above, a most serious barrier to documentation is the lack of incentives to model builders: it simply takes too much effort to record the modeling process, and recording is not an inherently stimulating task. Accordingly, any effective record keeping procedure should be as simple and automatic as possible.

The computer has the capability to elicit information from participants in a structured manner. For example, a policy analyst might specify documentation needs at the outset of the project. The director of the model building effort might then translate these specifications into questions to be administered by the computer; a filing feature would save all of the answers in a single file. A more automated approach might include a prestructured program which would elicit standardized information; it might even inquire about the stage of the modeling process and seek information relevant only to that stage.

But perhaps more important than these structured record keeping procedures is the ability of the computer to store and retrieve records of computer-based communication automatically. In his survey of documentation studies, Gass [11] concludes that:

> The final form of a computer model is a function of its origins (who wanted it and why) and its total evolutionary history. The true understanding of a model and its possible utility can only be accomplished by documentation of this history.

To capture the complexity of the model's history, the record keeping process should be more than after-the-fact statements about the process. A computer transcript might well preserve the major decisions, as well as the arguments for and against these decisions. A monitoring program might record important information about the interaction process, like the fact that a key resource person was absent from the discussion for two weeks during which several critical decisions were made. Such information might then lead to questions about resources which might be missing from the model--an important step toward validation.

Of course, both transcripts and monitor data might be as unmanageable as the 1,000-page reports that users presently complain about; however, with the process accurately recorded, it may be easier for builders--or *users*, if they have been participating--to review and edit the transcript than to reconstruct the process from memory or notes that have been kept with varying degrees of discipline.

SPECIAL PRESENTATION FORMATS

A third need, which is high on the list of priorities for improving the modeling process, is better formats for presenting models and model results to users or other builders, as well as formats for conceptualizing the model as it is being constructed. Graphic presentation formats seem especially valuable here. For example, diagrams and flow charts could allow builders to describe their models in a way that is more readily understandable and more easily criticized than computer documentation. Mar himself points to the need to "link the current and emerging graphics capability of computers to modeling applications" [20].

The computer is, in fact, capable of producing very sophisticated graphics. Current possibilities range from the production of simple bar charts and line drawings to three-dimensional "sketching" using the computer in an interactive mode. The major limitations at present include problems with terminals and the lack of easily used *interactive* graphics packages. There are a few terminals--perhaps one percent of all terminals presently in use--that can reproduce the very fine, detailed graphics that a computer can produce.* Some very powerful graphics software has been designed for these terminals, but this software is incompatible with the more common paper-printing terminals that have very coarse rasters and, therefore, can reproduce only very coarse graphics.

The second problem--the need for interactive graphics packages--is a user-interface problem. Graphics packages are subroutines that produce a selected form of graphic when the user specifies data and parameter choices. The interface between the user and the subroutine is a FORTRAN program, which is typically written for each specific need. Unfortunately, users who are unfamiliar with FORTRAN or who do not want to write a special program every time they want a graph need a general-purpose program that would serve as an interface. The easy access provided by such a program would allow builders to use graphics not only in conceptualizing the model, but also in communicating it to others.

*One barrier to widespread use of these terminals is cost: the user will need to invest about $5,000 for a graphics terminal; basic paper-printing terminals cost around $2,000 and are much more widely available at present. Thus, the cost difference to the user is significant.

STRUCTURED INTERACTION

Beyond the need for record keeping and graphic presentations, the problems in the modeling process suggest the need for a variety of programs that structure communication to meet specific needs. For example, Holling and Chambers suggest that an "interaction matrix" would help to systematize the efforts of various modelers working on submodels of a larger model [16]. The interaction matrix would map the relationships (interactions) among the multiple variables in the model; the use of such a matrix would encourage an explicit discussion of the assumptions of each modeler and would thus be especially valuable for illuminating differences in perceptions that may arise from differing disciplinary perspectives.

A structure that would encourage a modeler to specify the degree of accuracy of various components and data in the model would be a small but important step toward improving validation procedures. Another structure might define a procedure for challenging the validity of data inputs, as suggested by Brewer and Hall [3]. Structures that would allow human participants to play roles in a simulation model are also needed. Finally, there is a series of structural modeling techniques--actually premodeling procedures--which could be programmed and made available in a computer conference.

Not all of these structures need to be formal, computerized routines. Yet the computer can theoretically provide this kind of assistance just as it presently assists modelers in managing large amounts of data to be processed in the complex sequences that constitute a model.

USER TRAINING

Finally, there is a set of communication needs associated with training the user of the model. Particularly important here is the need for "conversational" computer languages that do not require a knowledge of special terms and procedures. Such user-oriented languages may, according to Mar, allay fears of computing that can inhibit use of the model. A computer conferencing system, which is simple and easy to use, may also serve as an introduction to more complex computer procedures. At the same time, the focus on training should not substitute for efforts to document models and make them easy to use.

SOFTWARE AIDS FOR THE TECHNICAL CORE OF MODELING

The primary role of the computer--and hence approaches to modeling software--has always been at the technical core of the modeling process. This technical core includes the specification of relationships among variables in the model and the translation of these relationships into computer operations, as well as the actual execution of the program with various inputs. These operations introduce some of the skill barriers noted in the previous chapter. The most basic strategy for improving the modeling process has been to reduce these skill barriers by developing specialized programming languages. A computer model can certainly be constructed using a universal language such as FORTRAN, but special-purpose modeling languages ease the task and also promote an understanding of the model by making the source code listing easier to comprehend.* Numerous such languages have been developed; DYNAMO, SIMULA, SIMSCRIPT, and GPSS seem to be the most widely used.

This basic approach has been extended with software systems that attempt to make the language more powerful and more interactive. For example, Mills, Fetter, and Averill [22] have developed a Conversational Modeling Language. This system allows the builder or user of a model to change, add, or delete various segments during the running of a simulation; they can thus alter the model structure interactively, defer programming of unlikely situations until they actually occur, or request only a sample of the statistical analysis before proceding with the entire analysis. A special English-like language within the CML allows the builder or user to define models in terms of dimensions of the model, variables, and equations that relate the variables along the dimensions.

Another computer-based system is the TROLL Econometric System [17]. TROLL is an interactive computer system with packages for standard regression analysis and experimental regression methods. It also provides a number of capabilities to support computer simulation, including the ability to share models and data among consenting users. In addition, TROLL provides access to the NBER Time-Series Data Bank, allows on-line editing and updating of data and models, and provides a graphics package for displaying time plots, histograms, scatter plots, n-dimensional point cloud manipulation, star plots, and others.

The NUCLEUS system of Battelle Memorial Institute is a dynamic simulation and modeling system. It is a high-level (and hence powerful) programming language which is also conversational, permitting construction of models by those who are not computer oriented. It is also an interpreter for dynamic simulation modeling; it thus allows simultaneous creation and execution of operations. It includes a data base management component for the retrieval of data and analysis of data fits as well.

Another example of a modeling aid is the SPEAKEASY system developed at Argonne National Laboratory [5]. Unlike a language such as FORTRAN, which requires multiple instructions for operations involving structures like arrays, vectors, or matrices, SPEAKEASY allows direct operations on such structures. A special dynamic storage scheme is available for defining and retrieving these structures. In addition, libraries of precompiled routines can be appended to the SPEAKEASY processor to extend its basic language capability. Output to the user can be presented using SPEAKEASY's extensive interactive graphics features.

The Scientific Data Base System of Lawrence Livermore Laboratory (LLL) addresses the need for data management. Its purpose is to provide access to raw and reduced experimental data by the 2,000 scientists at LLL, with interfaces to various processing packages. Another data management system is presently being developed at the Department of Energy. When complete, it will include network access to several data bases, a library of analysis programs, and computer conferencing and mail services.

Siegfried Dickhoven [7] has proposed the development of a "Model Base System," a more sophisticated system that stresses three concepts: modularization, software interfaces, and wide-range processors. By modularization, Dickhoven means the development of model components that can be used in a variety of larger scale models representing different types of systems. He also envisions a series of interface programs that would allow the modeler to link modeling tools with database systems or analyze packages without creating their own software. Finally, wide-range processors would support the construction and processing of models of different types (for example, dynamic vs. econometric models).

Most of these software aids are designed for a single modeler or a small, localized modeling team and for the highly technical tasks at the core of the modeling process. However, as the survey of modeling evaluations suggest, these technical tasks are embedded in a complex and problematic communication process. An alternative approach to software is thus to focus on the communication needs and computer capabilities noted above, on the assumption that the technical tasks will also benefit from improvements in communication. This is the approach we have adopted at the Institute for the Future.

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*Even so, it has been estimated that up to 70 percent of all simulations are realized using FORTRAN [8].

A COMMUNICATIONS APPROACH TO MODELING SOFTWARE

Specifically, we are now developing a system that will have as its core a communications facility--a computer conferencing system. This is an extension of the PLANET system developed previously at the Institute. PLANET is an assembly language program that is presently offered on two commercial networks. It supports communication among groups of up to 36 people at one time; up to 100 participants may be registered in a "conference." A conference organizer sets up the activity, giving it a name and indicating the list of participants. Once the conference is established, participants can communicate with one another via public, private, or anonymous messages. Public and anonymous messages are recorded in the conference transcript; private messages are seen only by the addressee. The transcript can be reviewed according to various criteria, including author, date, entry number, or some keyword. Users need not have any previous computer experience, as the system is almost entirely an English-language system.

To extend this system to meet the communication needs of modeling, we are adding the following features:

- Programs as participants. This feature will allow the organizer of the conference to include programs that are available on the network as participants in the conference. Thus, to run a program in the course of a conference, any participant can simply address a private message to the program. After the program has been run, the participant can automatically enter the results into the public transcript. This feature should be particularly valuable in using premodeling programs, such as KSIM, interactively.

- Bridge to text-editor. Conference participants may not wish to enter the entire transcript of a program run into a conference. Instead, they may prefer to edit large portions of it. To assist them, we will build a software bridge to the TECO text-editor; this software will allow TECO commands to be used in editing any public or private messages in PLANET before it is transmitted.

- Interaction matrix. This premodeling aid will encourage systematic discussion of the interrelationships among variables under study. It will be available in the same way as a program, but will include a capability for aggregating the group's responses rather than simply displaying a single participant's responses.

- Degree of precision charts. As noted above, modelers need a structure for specifying the degree of precision of any segment of the model as well as the model as a whole. This feature would use the flow-chart capability to elicit and process information about the degree of precision.

- Graphics. Since a number of graphics programs have already been written, we do not intend to create a new program. Rather, we will focus on developing software that will allow modelers to use an existing program interactively. Specifically, we have selected the Graphics Compatibility System (GCS) designed by the Army Corps of Engineers. The GCS consists of a set of FORTRAN subroutines for displaying two-dimensional graphics. It contains a set of terminal drivers ranging from teletype-compatible terminals (such as the Texas Instruments Silent 700 series) to advanced graphics terminals (such as the Tektronix 4000 series).

- State-of-the-model display. Another feature to be implemented once the graphics capability is in place is the ability to display the state of the model. This display will be a flow chart with annotations about data availability, state of various subroutines, and perhaps sample output.

CONCLUSION

Clearly, there are difficult theoretical issues in modeling that go beyond the boundaries of computer science. One of the most serious is the lack of theoretical understanding within individual disciplines to deal with the modeling problems; such theoretical development is a necessary prerequisite to more refined modeling procedures. Even within the range of computer science issues in modeling, there are some that are not related to communication. But the review of evaluations of modeling suggests that communication issues are perhaps the most *obvious* barriers to more effective modeling. Thus, by focusing our attention on these obvious problems, we may be able to lay the foundwork for more productive solutions to the technical and theoretical issues in the middle stages of the modeling process as well.

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