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REPORT TO THE CONGRESS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Ways To Improve Management Of Federally Funded Computerized Models

National Bureau of Standards
Department of Commerce
General Services Administration

The Department of Commerce needs to formulate standards for, and the General Services Administration should provide guidance to, Federal agencies for improving management of computerized models.

Because of the need for and absence of standards and guidance, GAO developed a phased approach which identified major activities necessary for planning, managing, and controlling computerized model development projects. Experienced model developers and users indicated considerable need for this type of general management guidance. The guidance should help to

--reduce wasted expenditures for models not used,
--reduce cost overruns, and
--initiate model development efforts that will better satisfy demands placed upon them.

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-115369

To the President of the Senate and the
Speaker of the House of Representatives

This report describes ways to improve management and development of federally funded computerized models. We reviewed the development and use of computerized models because of their large costs.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Secretary of Commerce and the Administrator of General Services.

Comptroller General
of the United States

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ABBREVIATIONS

GAO	General Accounting Office
GSA	General Services Administration
NBS	National Bureau of Standards

COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

WAYS TO IMPROVE MANAGEMENT OF FEDERALLY FUNDED COMPUTERIZED MODELS
National Bureau of Standards
Department of Commerce
General Services Administration

D I G E S T

A computerized model uses mathematical and logical rules and methods to represent how a process, physical object, or entity, such as an organization, can be expected to react under different conditions during a given period of time. Such models are used in many ways and in a variety of areas to help in managing Federal programs.

GAO identified 519 federally funded models developed or used in the Pacific Northwest area of the United States. (See app. III.) Development of these models cost about $39 million. Fifty-seven of the models were selected for detailed review, each costing over $100,000 to develop. They represent 55 percent of the $39 million of development costs in the models. (See app. IV and V.)

Although successfully developed models can be of assistance in the management of Federal programs, GAO found that many model development efforts experienced large cost overruns, prolonged delays in completion, and total user dissatisfaction with the information obtained from the model. (See pp. 10 to 14.)

GAO identified many of the problems that caused ineffective and inefficient use of the models. No Government-wide guidance was found that would help Federal agencies avoid these problems in their model development activities. This lack of guidance prompted GAO to develop a phased approach which identified major activities necessary for planning, managing, and controlling model development efforts. (See p. 15.) Most of the organizations which developed the models GAO reviewed in detail agreed that these factors

should serve as a basis for development of Government-wide guidance and standards.

Although the General Services Administration and the Department of Commerce agreed with the need for Government-wide guidance to assist managers and developers avoid development problems, neither agency stated when they were prepared to take action. (See p. 28.)

GAO recommends the Department of Commerce formulate standards for, and the General Services Administration develop and provide guidance to, Federal agencies for improving management of computerized models. GAO believes prompt and positive action should be taken by these agencies on our recommendations to provide the needed guidance and standards. The findings in this and previous GAO reports show that much of the money spent by the Government for model development is wasted.

A minor investment by General Services Administration and Commerce in the formulation of guidance and standards as recommended in this report could save the Government millions of dollars in model development costs and make modeling a more efficient and effective tool for managing Federal programs.

CHAPTER 1

INTRODUCTION

WHAT IS A COMPUTERIZED MODEL?

Federal programs are growing larger and more complex every day; the Government manager must deal with more facts and figures, evaluate more situations, and make more decisions more rapidly than ever before. To do this he has used the computer's ability to store and process vast quantities of data, to assist in comprehending issues and developing answers for some of the most complex social, economic, and technical problems of our day.

One important use of the computer is the computerized model. A computerized model is a computer program which uses mathematical and logical rules and methods to represent how a process, physical object, or entity, such as an organization, can be expected to react under different conditions during a given period of time. For example, the manager can have models represent such things as a transit system or the structure of a missile and he can determine the acceptability of a proposal before spending time and resources to build it.

A computerized model is generally not as complex as reality, because mathematical formulas are only representative of an actual situation. Also, because the model is based on assumptions of varying degrees of validity, results are not necessarily a true projection. Consequently, we should recognize these limitations when using models to assist in making decisions.

WHY ARE COMPUTERIZED MODELS IMPORTANT?

Successfully developed computerized models can be effective in assisting management of Federal programs. They have provided answers to questions where physical tests were either impossible or impractical to conduct. In some cases they have resulted in large savings when compared to noncomputerized methods of analysis. They have also had an important effect on the decisionmaking process in some Federal programs costing billions of dollars. The following examples show how models can contribute to the decisionmaking process.

--The military has sponsored development and use of a model which simulates the launching of a strategic missile. This model is used to evaluate the effect

of a nuclear explosion on the missile and its launch support system. In addition, it determines the mathematical probability of a successful launch under various conditions. The contractor informed us that this model cost about $150,000 and was apparently developed because of limitations on physical tests of this important capability.

--The military has developed a model which simulates the dispersion of radioactive materials accidently released in the ocean. This model is used to predict the spread of contaminants and assess their effect should a leak occur. Defense officials told us that the model was developed because physical testing using radioactive material would be impractical and dangerous. The model cost $107,000 to develop.

--The Government used a model to simulate the effects of stress on steel transmission towers. This stress is caused by the force of wind and ice on electrical transmission lines supported by the towers. This model computes the minimum amount of steel needed in a tower and may reduce manual estimates of steel requirements by 10 percent in a $50,000 tower. Because one tower design may be used an average of five times in each mile of transmission line, the use of this model could save $25,000 per mile of transmission line. The model cost about $150,000 to develop.

--A Government contractor has developed a model to assist in the design of liquid propellant rocket engines. Previously, engineers built and physically tested each engine design to determine its acceptability. Because they now use the model to test their engine designs, an acceptable design is achieved without spending the time and money to build each newly conceived rocket engine. The contractor informed us that this model cost about $112,000 to develop.

--The military has sponsored development of three computerized models which simulate the guidance and control of a short range, air-to-surface missile. These models were used instead of actual test flights to assure that the missile would fly properly. Defense officials informed us that development of these models cost about $870,000, and that they are an important part of the estimated $1.3 billion project.

--A local agency has a model which simulates the effect of population and employment on land-use planning. Agency officials told us that this model cost $120,000 and has been used to estimate the effect of a freeway bridge system planned for a major city, thus supplying important planning information for a $450 million interstate highway system project.

WHAT IS THE FEDERAL INVESTMENT IN COMPUTERIZED MODELS?

Although the Government's total investment in computerized models cannot be determined, our previous reports and reports by other organizations indicate that large sums of money have been expended to develop and use these models. Although several model users and developers were able to provide us with cost information, most could only provide a general estimate. One reason is that separate cost figures were usually not maintained when development was a part of a larger program or the everyday operations of the organization. In those cases where cost information was available from the model developer, costs incurred by the user were often not identified.

In our report on "Improvement Needed in Documenting Computer Systems" (B-115369, Oct. 8, 1974), we identified 644 federally funded computerized models in the New England area. These 644 models were first identified in our study "Auditing a Computer Model: A Case Study" (Case Study (CS-4), May 1973). Investment in 242 of these models totaled over $13 million--an average of almost $54,000 a model. In "Advantages and Limitations of Computer Simulation in Decisionmaking, Department of Defense" (B-163074, May 3, 1973), we identified about 450 active models (including simulation and games) in the Department of Defense. Investment in 104 of these models totaled over $28 million, an average cost of about $277,000 a model. In "Computer Simulations, War Gaming and Contract Studies, Department of Defense" (B-163074, Feb. 23, 1971), we stated that the fiscal year 1970 Defense-wide expenditure for computer simulation models was about $172 million.

Reports developed by private organizations also indicate the magnitude of investments. One of these reports included a survey of over 650 federally funded models in the social science field. Investment in 222 of these models totaled over $31 million. This is an average cost of about $140,000 a model. In addition, these reports showed that the problems the Government experienced in developing useful models were

not unique. These problems generally contributed to large model cost overruns, prolonged model development cycles, and users' dissatisfaction with information produced by the model.

SCOPE OF REVIEW

The objective of this review was to determine how Federal agencies could improve their management and use of computerized models. The need for improvement is quite evident from studies conducted by both the Government and private organizations.

The following examples represent some of the conditions previously reported in these studies:

--Management controls were needed to insure that no duplication of effort existed and that the information used in and obtained from the models was given appropriate consideration by decisionmakers.

--Generally, decisionmakers are not aware of the uncertainties inherent in the process of modeling and tend to place greater reliance on the information than may be warranted in the circumstances.

--Some models were not validated or could not be verified; thus, managers could not rely on the results produced.

--Some models were not used for their intended purpose due to poor communication and documentation between the user and the developer.

--Questions about alternative methods to modeling and simulation were seldom explored. Current procedures do not seem to include formal consideration of whether there is a less expensive, easier way to proceed or whether modelbuilding is actually the most appropriate technique.

--Most model development efforts lacked a clear definition of the model objectives and conditions to be portrayed; thus the developer had to guess what it was he was trying to model.

Our past studies and those conducted by private organizations showed that these problems were not unique to any particular geographical area of the Nation. We selected the

Pacific Northwest area of the United States for our review. We sent questionnaires to 538 organizations that appeared to develop or use computer models. These organizations included Federal, State, and local agencies; colleges and universities; and Government contractors. Responses were received from all 538 organizations and identified the development and use of 519 models costing about $39 million. Results of these responses are summarized in appendix III. For further review, we selected 57 models costing about $21 million from the total of 519 models. Each of these models cost $100,000 or more to develop. Information on the other characteristics of these models is summarized in appendix IV.

On the basis of our analysis of information gathered during this review, we identified those procedures which tend to improve the management and use of computerized models. These procedures are discussed more fully in chapter 4.

CHAPTER 2

NEED FOR IMPROVED MANAGEMENT

The Congress, recognizing the need for a Government-wide, coordinated management system for the economic and efficient acquisition, utilization, and maintenance of automated data processing equipment, enacted Public Law 89-306 (the Brooks Bill) 40 U.S.C. 759 (1970) in October 1965. This law gives the General Services Administration (GSA) broad authority for developing Government-wide guidance for automated data processing activities. The law also gives the National Bureau of Standards (NBS), Department of Commerce, responsibility for establishing Government-wide automated data processing standards. Neither agency, however, has yet provided specific guidance to assist Federal agencies in managing the development of computerized models.

GSA's responsibilities include developing, implementing, and monitoring Government-wide policy pertaining to automated data processing resource acquisition, management, and utilization. GSA is also responsible for providing guidance, assistance, and coordination to Federal agencies in their procurement and utilization of automated data processing services. The Department of Commerce has responsibility for establishing Government-wide automated data processing standards and is authorized to undertake necessary research and to provide advisory services to Federal agencies on automated data processing and related systems.

Our analysis of 57 federally supported computerized model development efforts showed that lack of this guidance was a factor directly contributing to the large problems experienced while developing 33 of these models. These problems resulted in cost overruns, delays in developing the models, and user dissatisfaction with the information produced by the model. Cost overruns totaled about $1.1 million to make some models responsive to user needs. Some development cycles were delayed up to 4 years beyond their original and revised completion dates. In some instances managers would not use the information obtained from the model because they were displeased with its reliability. The cost to develop those unsatisfactory models totaled about $1.6 million.

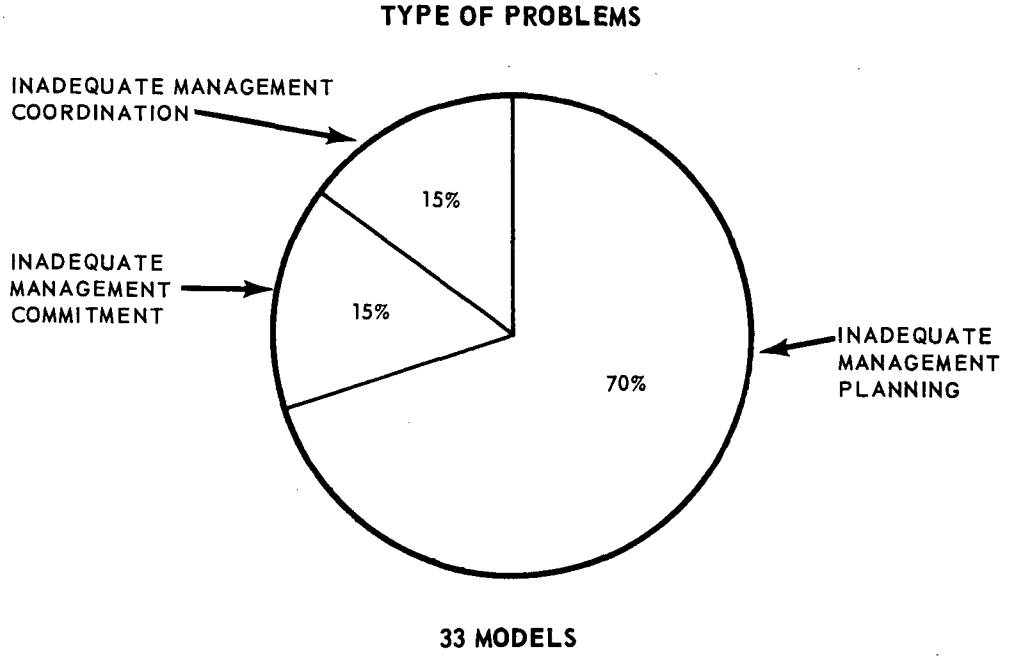
WHAT TYPES OF MODELS DID WE REVIEW?

About 70 percent of the models included in our review were used in aerospace research, water resource management,

weapons research, hydroelectric power management, or transportation planning. The remaining models addressed 12 other functional areas, including law enforcement management, electronic equipment design, medical research, and nuclear reactor planning. Additional information on characteristics of these models is in appendix IV.

WHAT TYPE OF PROBLEMS DID WE IDENTIFY?

Further analysis of the 33 models that experienced problems during their development indicated the problems could be grouped into 3 broad categories--those problems attributable to inadequate management planning, those attributable to inadequate management commitment, and those attributable to inadequate management coordination. The approximate relationship between these categories is depicted in the diagram shown below.



These three categories encompassed many different types of problems. Those problems which occurred most frequently and those which contributed most to cost overruns, prolonged development periods, and user dissatisfaction have been listed below. We noted that many of these problems were similar to those previously reported in our reports or reports prepared by private organizations.

1. Problems attributable to inadequate management planning:

   --Management did not clearly define the problem to be modeled; thus, the developer had to guess what had to be modeled.

   --The developer was not able to obtain the data needed to make the model function.

   --Management allocated insufficient funds to complete the model.

   --Management did not make workable provisions for updating the model for future use; thus, the model soon began to produce outdated information.

   --Management did not make provisions for evaluating the model.

   --Management did not clarify documentation requirements for the model. As a result, only the developer understood how it worked and the relationships maintained by the variables incorporated into it.

2. Problems attributable to inadequate management commitment:

   --Management did not actively participate in planning of the model. Thus, the model did not clearly reflect their needs.

   --Management did not understand computer modeling techniques and applications. Consequently, they could not effectively use information obtained from the models.

3. Problems attributable to inadequate management coordination:

   --Management did not monitor the model development effort on a continuous basis. Thus, management allowed development efforts to continue after they should have been terminated.

   --Managers did not coordinate the development effort with the developer. As a result, the model was developed without reasonable assurance that it would meet user needs.

These problems occurred regardless of the type of user or developer and were not related to the model's functional area, purpose, type of application, cost, or source of funding.

WHAT WAS THE EFFECT OF THESE PROBLEMS?

First, some of the models were not used after they were developed. Estimated costs of unused models ranged from $100,000 to $577,800 and totaled about $1.6 million.

Second, many of the models experienced cost overruns. These cost overruns ranged from $1,250 to $400,000 and totaled about $1.1 million.

Third, many of the models experienced prolonged development periods. These prolonged development periods ranged to 4 years before the model satisfied user needs.

Finally, several of the models required additional expenditures to complete. These additional expenditures were attributable to a variety of conditions, including validated changes in requirements after the development effort began. However, we were able to identify only $81,300 attributable to this condition. When discussing with model developers the effect of changing requirements on the development effort, this condition was not believed to be a major factor in the problems they experienced in developing a useful model. For this reason, we do not believe that changing requirements have had a serious effect on model development activities.

Model developers and users gave various explanations as to why these problems occurred. The reasons most frequently presented included unreliability of results, developers' inability to obtain necessary data, and users' failure to allocate enough funds to complete the model. Collectively, these problems prevented efficient use of the models in aiding management of Federal programs. Some detailed examples of these conditions are described in chapter 3.

CHAPTER 3

EXAMPLES OF THE NEED TO IMPROVE MODEL DEVELOPMENT ACTIVITIES

The examples discussed below illustrate what can happen when model development activities are not properly managed. These examples should not be considered as being all inclusive of the problems that can be encountered when developing a computerized model. However, they do illustrate the need for Government-wide guidance so that managers of these development efforts can avoid such problems in the future. These examples illustrate the more common problems experienced during model development efforts and serve as a basis for developing new procedures that should minimize the occurrence of problems in the future. These new procedures are described in chapter 4.

RESPONSIVENESS OF MODELS

Using their own employees, a Government agency developed a computer model to assist them in determining the natural and artificial recharge (inflow-outflow) of ground water in a large river basin. The model was initially to be used by a Federal and a State agency to study effects of irrigation on the water table. Size of available computer memory restricted developers' ability to make a single model that would serve these needs. Thus, three models were developed, each simulating effects of irrigation on the water table in a different part of the river basin. The model development effort was started in late 1968 and was completed in early 1973 at a cost of $400,000. This cost was shared by the two agencies.

Only two of the three models proved useful. The third model does not have enough data available on water table levels before irrigation activities to enable the model to produce reliable results. As described by the developer, the model cannot produce a good comparison of recharge activities before and after irrigation. As a result no one uses this model. This case illustrates the desirability of determining if sufficient data is available so that current and future applications of a model can be successful.

INADEQUATE EVALUATION PROCEDURES

The Government contracted with a California research firm to model the temperature of water released from dams.

The model's purpose was to provide a Federal agency with information for studying the effect of temperature changes on the river's animal and plant life. The model development contract cost was $50,000. Work on the model was completed in 1967 with approximately a 1-month delay in its completion and an $8,000 cost overrun. However, an additional $95,840 was spent to make the model responsive to user needs. This was spent to include other options in the model and to correct an option in the original model. The additional time and money expended on this project was attributable to several factors. First, management did not clearly define the problem to be modeled, and secondly, the developer did not make certain the model was operationally ready before delivery. These conditions illustrate the value of testing and validating a model before accepting it.

INSUFFICIENT USER PARTICIPATION IN MODEL PLANNING AND INADEQUATE MONITORING

A university was funded for $100,000 by a Federal agency to model the movement of vehicles on forest roads used for timber access, fire protection, and other purposes. The model was to assist the Government agency in evaluating alternative designs for forest roads. The project was started in January 1969 and completed by the university in January 1971. An additional $60,000 was paid to a private research firm to evaluate and test the model.

The model did not adequately represent the problem to be solved and was not used. The model was developed for determining turnouts (a widened portion of a road where cars may pass) on single-lane roads but not for designing roads with more than one lane. The Government seldom builds single-lane roads. The user within the agency cited insufficient participation in model planning and inadequate monitoring of the model development by the agency as reasons for the unsuccessful effort.

INADEQUATE DOCUMENTATION, POOR USER/DEVELOPER COORDINATION, AND INSUFFICIENT PROBLEM DEFINITION

A university was given about $45,000 by the Government to study the long and short range effects of alternative State regulatory policies on the biological and economic performance of U.S. salmon, halibut, anchovy, and king crab

fisheries. These models were designed to help the Federal agency and States evaluate fish management strategies used and proposed by the Pacific Coast States. The project was started in June 1970 and planned for completion in 1 year. The project experienced several delays and after numerous extensions the model was finally completed in July 1974 at an additional cost of $65,000.

At the time of completion, only the salmon model of the four fishery models was being used and this only to a limited extent in developing an expanded, more detailed model of the salmon fishery. The anchovy and king crab models encountered questions concerning the costs of anchovies and the life cycle of the king crab used in the assumptions.

The halibut model had not yet been evaluated by a user at the time of our review. An agency official stated that these problems occurred because the primary model developer died and left poorly documented work. In addition, the official cited poor user/developer communication and cooperation and insufficient problem definition.

INADEQUATE USER PARTICIPATION IN DEFINING THE PROBLEM TO BE SOLVED

A Government agency awarded a grant for $328,200 to a university to model alternatives in forest land use of a river basin in western Washington. The model was intended to help Federal and State agencies and other interests make forest production, recreation, wildlife, and fishery decisions. The project was started in June 1972 and a working model was completed in May 1974. In June 1974 an additional $249,600 was provided by the agency to document and validate the model for use outside the university. The additional effort, scheduled for completion in November 1975, was planned to make the model usable by two Federal agencies and a State agency.

An official of one of the Federal agencies told us that after the model was modified and some data was corrected, the agency hoped to be able to use it. Officials of the other two agencies said that they did not expect to use the model even with better documentation. The model does not meet any specific needs within these agencies. For example, a State agency official told us the State had little land ownership in this particular river basin and had no need to use the model. Lack of participation by

these agencies in model planning, especially in defining the problem the model was intended to solve, was cited as a reason for the reluctance to use it.

INADEQUATE AGREEMENT ON MODEL SPECIFICATIONS

The military contracted with a firm to model interaction between attacking aircraft and different types of antiaircraft forces. The model was intended to help the military improve and standardize its methods and techniques for evaluating interaction of offensive and defensive systems. The project was started in late 1969 and delivery of an operating model had been planned in December 1970 at a cost of about $900,000.

The model developed was not satisfactory to the intended user and required an estimated $400,000 in additional costs and 2 additional years to become fully responsive to user needs. The developer told us the model's specifications, including problem definition, model logic, algorithms, 1/ and input-output formats, were not fully agreed to before initiating the final design effort. Although contact was maintained between the user and contractor, officials from both organizations indicated inadequate contractual monitoring and development evaluation procedures were additional reasons for the cost overrun and delay in completing the model.

INADEQUATE MONITORING AND LITTLE USER INVOLVEMENT

Two universities were awarded a grant by the Government and a State agency to model water movement and use in a river basin. The model was intended to give the State a tool for managing water use in the basin. The project leader responsible for the model development stated that because of the project's size and complexity, the model was segmented. The segments were undertaken jointly by two universities. The project was started in July 1970 and development was completed about July 1973; however, an additional year was required to document the final product. We were told the cost of the model was about $300,000.

1/An algorithm is a step-by-step procedure for solving a mathematical problem.

The developed model could not be integrated into one system as planned and has never been used as intended. Lack of monitoring and little involvement by the user were cited by the project leader as reasons for this unsuccessful effort.

The repetitive nature of conditions described in this chapter illustrates a need for Government-wide guidance that will assist users and model developers to reduce cost overruns, to shorten model development efforts, and to make models more responsive to user needs. The principal factors that should be considered when initiating a model development effort are described in the next chapter.

CHAPTER 4

FACTORS TO CONSIDER WHEN MANAGING DEVELOPMENT OF COMPUTERIZED MODELS

The purpose of this chapter is to describe factors to consider when managing computerized model development activities. We believe the five-phased approach for the factors presented in this chapter can greatly improve management of these activities and make computerized models more responsive to user needs. The more responsive these models are to user needs the more effective and efficient they should be in assisting management of Federal programs. Most of the 40 organizations that developed the models we examined supported the phased approach concept.

The following factors are the product of our analysis of management weaknesses which are inherent in modeling development problems. These factors also suggested procedures which are intended to prevent those problems. These procedures are intended to serve as a reference document for managing development of computerized models. This flexible guidance should help the manager in making essential model development decisions.

Proposed considerations for the management of computerized model development are divided into five separate phases: problem definition, preliminary design, detail design, evaluation, and maintenance. In each phase we describe suggested specific duties and responsibilities of the user and the developer. In our previous reports, we have emphasized the importance of documentation. Requirement for documentation should be met as necessary in each of the five phases.

The user may contract for as many of the phases as he feels is appropriate. However, the user has to have the flexibility, whether the phase is being done in-house or under contract, to stop model development whenever he determines it is no longer feasible. This could be at any point in the development effort, but a definite decision should be made at the end of each phase whether to go to the next phase or not. This would allow the user to stop the project with a minimum commitment and expenditure of funds compared to the total project costs.

FIVE PHASES OF MODEL DEVELOPMENT

Problem definition phase

This phase is primarily intended to describe those tasks that should be carried out by the user before agreeing to a model design. Additionally, the phase also describes design considerations and when appropriate the contractual relationships which the user must determine before deciding whether a preliminary design effort should begin.

Following are the tasks that should be accomplished and, where appropriate, documented.

--Define the problem to be solved, including identifying various elements that pertain to the problem and its solution.

--Obtain commitment for model development from appropriate management officials.

--Determine that a successfully developed model will be used to help solve the defined problem.

--Obtain expert advice on the best approach to solve the problem, including whether an approach, such as modeling, would be appropriate. This procedure should include a search of the literature for models already developed to solve the same or similar problems.

--Estimate frequency that the model will be used (e.g., one-time or repetitive use) and the possible need to update it in the future.

--Determine degree of accuracy needed from the model.

--Estimate benefits expected from using the model and the costs, if determinable at this point, of developing, operating, and maintaining the model.

--Evaluate qualifications and capabilities of potential model developers.

--Determine whether the model will be developed within the organization or by another organization (e.g., Government contractor) and identify the developer.

--Determine the extent of training necessary to provide

the user organization with the background to operate and maintain the model.

--Determine the type of modeling techniques (e.g., linear programming or simulation) to be used.

--Implement requirements concerning

1. ease of model use, and

2. data support; i.e., availability of information needed for developing model and input data needed to run and verify the model.

--Define extent of modular programming; i.e., the extent the model will be segmented into self-contained routines for efficient future updating.

--Determine the developer's training program for the user.

--Construct the model test plan and evaluation criteria (e.g., specific test case and test data for the model) to determine if the model meets the user's needs.

--Specify the estimated requirement dates for completing the preliminary design phase, the detail design phase, and the evaluation phase.

--Document requirements for the model.

--Establish user monitoring procedures and developer-reporting procedures during model development.

--Develop a procedure for maintaining control over model code, test data, and documentation.

--Define progress payment procedures for the various phases.

--Determine the extent to which the user can require changes during the development and price charges (e.g., amount per staff-hour) for them. This should be limited to minor changes that do not exceed specific criteria; e.g., a given dollar amount.

--Determine developer's availability after completing the development, including price charges (e.g., amount per staff-hour) for additional work requested by user.

During this phase, the user should be acquiring a clear definition of the problem and a description of the model development considerations. If the information being acquired during this phase indicates development should be stopped before the end of the phase, the user should be prepared to terminate development at this point. To determine whether to continue into the next phase, the user should consolidate and thoroughly review work completed during this phase. At this point the user should be confident that his needs will be met by the model without making changes to decisions that have been made. If the review indicates the user's needs can be met, the development effort should proceed to the next phase. If user's needs cannot be met, the development effort should be terminated. If the decision is made to proceed to the preliminary design phase, a report should be prepared which provides specific guidelines to be followed in the remaining phases. In effect, guidelines should represent contractual responsibilities for the development.

Preliminary design phase

This preliminary design effort includes specification of the information content, general programming logic, and model algorithms necessary to develop a useful model. Preliminary design of the model should be conducted by the developer with information input and direction provided by the user.

The user should be certain that the developer has the information he needs to accomplish the following tasks during this phase.

--Defining input variables and input formats to be used by the model.

--Defining implementation requirements concerning:

1. Programming language of the model.

2. Time and cost constraints for development, operation, and maintenance of the model, including data input preparation.

3. Availability and adequacy of computer equipment and software.

4. Estimated program running time.

--Describing the model's output.

--Specifying input and output media (e.g., punch cards, tape, plotter, or printers).

--Describing the general program logic of the model, including basic flow charts with input, processing, and output described.

--Defining the algorithms to be used; that is, defining the mathematical and logical relationships to be used in the model.

--Defining the program modules and their structural relationships.

--Specifying assumptions and limitations of the model; that is, any major differences that may result from translating the problem to the model algorithms.

--Making minor changes with the proper documentation, including a narrative description justifying the changes. If the problem must be redefined or substantially revised, model development should be terminated.

--Determining the amount to be paid the developer during the detailed design and evaluation phases if not already contracted.

--Reevaluating costs to be incurred and benefits to be realized from use of the model.

If the user determines the model is no longer feasible during development of the factors in this preliminary design phase, he should stop development. At completion of this phase, the user should consolidate and thoroughly review work completed on these factors. At this point the user should be confident that all of the specifications necessary to develop a useful model have been identified and agreed to and will not need to be changed during the following phases. On the basis of this determination the user decides whether to continue into the next phase. If the effort is to be continued the user must determine the contract or work agreement process to be followed. The contract or work agreement should include specifications for the model and the control, documentation, and report requirements of the following two or three phases, as applicable (detail design, evaluation, and maintenance).

Detail design phase

The developer designs the model logic and prepares detailed programs. Briefings should be held periodically between developer and user. One purpose of these briefings is to provide the user with the knowledge and confidence necessary to apply the model. During this phase, the user should continuously reevaluate the design being implemented and, if necessary, should recommend minor changes within the scope of the contract or work agreement, or terminate the development if the model is no longer feasible or needs a major change. The user should always be available to the developer to answer questions and provide needed information. The following should be accomplished and documented.

--Developer's design of the detailed programming logic of the model.

--Developer's preparation of the computer programs.

--Developer's system testing of the computer programs and, if applicable, the program modules.

--Developer's sensitivity testing of input to the model (i.e., examining the extent to which changes in input to the model affect results of the model). Included should be a test of the model's limiting (extreme) values.

--Developer's preparation of a user's guide and other programming documentation.

--Results of the periodic briefings between developer and user.

--Changes requested by the user and the position of the developer on making these changes.

Before continuing into the next phase the user should consolidate and thoroughly review the work completed in this phase. This review should provide the manager with sufficient updated information to determine the adequacy and responsiveness of the development effort at this point. If the model has been adequately developed to meet the user's needs, procedures for evaluation of the model should be established and carried out in the next phase. If the user's needs cannot be met development should be terminated.

Evaluation phase

This phase provides for the final check of the model as a whole. This operational testing supplements the evaluation of individual model programs conducted during earlier phases. The user has ultimate responsibility for evaluating the adequacy of the developed model. Actual evaluation of the model, however, may be done by the user, both user and developer, and/or an independent third party. Evaluation of the model is done according to the evaluation criteria and test plan established in the problem definition phase. Evaluation includes model validation and the determination of compliance with previously established agreements. Validation is using selected data to test agreement between model behavior and the physical system it is to describe. If, during the validation process, it is determined that the model will not meet the user's needs, development should be stopped.

The following items should be accomplished and documented by the user and/or independent third party with appropriate assistance from the developer.

--Determining developer's compliance with contractual agreements and reasons for any noncompliance.

--Evaluating model output with evaluation criteria established in the problem definition phase.

--Evaluating adequacy of the developer's sensitivity testing and the results obtained.

--Determining validity of the individual mathematical relationships in the model and whether all relationships are valid with respect to each other.

--Evaluating the model using actual data (i.e., actual situation data where possible) instead of test data, including the use of data for which the results are already known or can be calculated manually.

At the completion of this phase, the user should prepare a report based on the evaluation work. This report should include the user's overall satisfaction or dissatisfaction with the modeling effort and the final model design. A decision should then be made as to whether or not the model is usable. If it is not usable the development effort should be stopped.

Maintenance phase

The Federal agency that sponsored model development establishes procedures for updating the model and for obtaining from the users their comments on adequacy of the model and whatever changes they made to the model. The developer should be available for assisting the user after completion of model development in accordance with the agreement established during the preliminary design phase. Agency management should obtain from the user an abstract of the model application to provide information to others. A complete inventory of all of its successful and unsuccessful models should be maintained by each sponsoring agency to enhance transferability of models and prevent duplication of development effort. Also, periodic reports should be prepared showing any changes made to the models and indicating current status of the models. When the model can no longer meet user needs its maintenance should be stopped and the status should show it is not usable.

During this phase the agency responsible for model development assures accomplishment of the following.

--Document all changes to the model, including reasons for the changes.

--Maintain a list of all model users and obtain their comments on its adequacy and documentation of their changes to it.

--Maintain a duplicate copy of the model program(s).

--Prepare an abstract of the model application for agency management and update annually. The abstract should include such information as the model title, a brief description of the model purpose, name and address of the developer, the type of computer equipment needed to run the model, and the operating cost.

ADDITIONAL CONSIDERATIONS

We believe a contract with a breakpoint at the end of each phase should be used so that a developer cannot proceed from one phase to the next without written approval from the user. Each phase or breakpoint should be separately priced so that a termination at the end of a specific phase will limit the Government's liability under the contract to those costs incurred for the contractor's performance up to the breakpoint. This type of contract gives the user the opportunity

to review progress of the modeling effort to see if it has shown the potential for developing a useful model before proceeding with the next phase. In addition, the contract should include a provision for terminating it at the Government's convenience at any time during any of the phases. Such a provision would enable the Government to terminate the contract between breakpoints and not have to incur unnecessary costs by allowing the contractor to proceed to a breakpoint. A similar but less formal procedure should be used for in-house modeling development efforts. A contract with similar provisions has been used by the Air Force for procuring equipment.

In summary, the factors represent some suggested procedures for model development. They are intended to illustrate at least one method of enhancing the user's perspective of modeling and reducing the chance of failure during model development. They are presented in a form that (1) distinguishes five separate phases of model development, (2) promotes a more thorough early investigation of the nature of the problem and of possible solution methods, and (3) provides a method of controlling the commitment to a modeling effort during the model's development period.

CHAPTER 5

RESERVATIONS OF MODELING MANAGERS AND TECHNICIANS

Responses we received from experienced modeling managers and technicians clearly emphasized a need for the general guidance as presented in the previous chapter. However, these same individuals also showed some reservations about implementing such guidance in the Federal contracting area.

ARE THE FACTORS FLEXIBLE?

The primary concern was the fear that the guidance factors could become requirements for all modeling efforts. Respondents noted that model development efforts are not all the same. They differ in size, complexity, and level of the technology being applied. In addition, the contractual process as well as the contractual management relationship will vary from project to project. Respondents pointed to these structural and management differences as evidence of the need for flexibility in implementing any set of guidance factors. More specifically they noted the need to allow the manager freedom in determining which factors to consider and the level of activity required. Some respondents did not believe that guidance factors need be formally applied to models developed and used in the same organization because of the close working relationship between the users and developers. They did, however, agree that procedures included in the phased approach to model management are sound.

The guidance factors are not intended as absolute requirements. Rather, they represent a preliminary listing of procedures a manager should consider when undertaking a model development effort. These techniques are meant to provide the manager with an awareness of the total development process--not necessarily to establish a checklist for compliance. Most of the people we talked to stated that such guidance would be useful if it remained flexible.

IS SEPARATE FUNDING PRACTICAL?

We were told that potential contractors would hesitate to do any preliminary work if followup work was not guaranteed. The suggested breakpoint contract for a modeling effort does not guarantee work on the following phases. The contract gives the model manager the responsibility of assessing the evidence at the end of each phase before

giving approval to proceed to the next phase. It also allows contract termination at the convenience of the Government at any time during any of the phases. This gives the manager the opportunity to stop development if the model is not going to be useful. We do not believe that the breakpoint contract will act as a disincentive because the contractor knows under what conditions he is contracting for and will know how much he is going to receive at the end of each phase if the contract is terminated at one of those points.

IS COMPETITIVE PROCUREMENT DISCOURAGED?

Some respondents felt the emphasis on the early exchange of information between the user and the developer would encourage sole-source procurement. We do not intend for our guidance factors to suggest that competitive procurement is discouraged. The user and developer relationship we outline in the problem definition and preliminary design phases is meant to address both sole-source and competitive procurements. We also do not intend for the factors to restrict or exclude the use of any specific type of contractual agreement. However, we believe the breakpoint contract will keep the Government's cost to a minimum. The factors are intended to complement the contractual agreement by providing the manager with a source of forethought in his planning of the development effort.

We believe that consideration of the factors contained in the phases would help contractors to submit more responsive proposals and the manager would have better criteria for proposal evaluation and selection. This should result in more open competition.

ARE RESEARCH EFFORTS EXCLUDED?

Some respondents were hesitant to totally accept the phased approach as being applicable to research activities. Several felt the elements were too structured for research activities and would inhibit the creativity and flexibility necessary in this area.

To the contrary, the phased approach described in this report is based on the scientific approach to problem solving. Creativity should be enhanced because of the flexibility available within the systematic procedures suggested for reaching a solution. We believe that the problem definition phase is an excellent first step for any research project, including modeling activities. The remaining

phases are flexible enough to provide sound guidance regardless of whether the effort is considered to be a research or operational project.

ARE SMALL MODELING EFFORTS EXCLUDED?

A few respondents felt that the phased approach should not apply to inexpensive models and models concerned with narrow problem areas. They explained that such model developments are usually small and inexpensive and were not worth the extra time or expense of answering all the elements.

We believe that all modeling efforts--large or small, complex or simple, costly or inexpensive--can benefit from the management awareness and development logic provided in the consecutive phases. They are intended to point out what management should consider in a model development perspective. They are not necessarily intended to be requirements or a system for compliance. The manager determines how much detail the project needs.

The majority of people we contacted responded favorably to the guidance factors developed within the modeling phases. Most of those who experienced problems agree the items will be helpful to some degree in preventing recurrence of the types of problems identified in a wide range of modeling activities.

SHOULD THERE BE FEWER OR MORE PHASES?

A few respondents felt that the number of phases we propose should either be increased or decreased to provide a more realistic management approach to model development. These comments indicated no real concern about the total perspective provided by the five-phased approach of the management elements. Only the number of phases was discussed.

CHAPTER 6

CONCLUSIONS, RECOMMENDATIONS, AGENCY COMMENTS, AND OUR EVALUATION

CONCLUSIONS

Our review indicated existing management practices are insufficient to adequately resolve problems associated with the development of computerized models. Model developers, users, and sponsors generally agreed the number of problems experienced in model developments could have been reduced by using management guidance designed specifically for this type of activity. In response to this need, the guidance factors developed in this report can serve as a starting point for development of effective modeling activity guidelines for Federal agencies. We believe guidelines should be formulated as soon as possible because good models can effectively assist in the management of Federal programs.

RECOMMENDATIONS

To improve development and procurement of models, we recommend that the Secretary of Commerce

--formulate Government-wide standards pertaining to development and procurement of computerized models and

--coordinate and obtain advice for the establishment of these standards from the heads of Federal agencies, including the Administrator of General Services.

In addition, we recommend the Administrator of General Services

--develop and provide Government-wide guidance pertaining to development and procurement of computerized models and

--coordinate with the Secretary of Commerce and incorporate the Government-wide standards Commerce will formulate relating to computerized models.

AGENCY COMMENTS AND OUR EVALUATION

Department of Commerce comments

The Assistant Secretary for Science and Technology, Department of Commerce, generally agreed with our recommended approach to model development and the recommendation for action by the Secretary of Commerce and the Administrator of General Services. (See app. I.) However, some reservations regarding emphasis were expressed as follows.

--Modification of the first two model development phases--i.e., problem definition and preliminary design--to allow greater freedom for technical discovery before being committed to a design approach.

--Amplification of the importance of documentation to the model development process.

--Greater emphasis on the voluntary aspects of standards and guidelines.

On the basis of these comments and subsequent discussions with the National Bureau of Standards, we modified, where appropriate, the report's discussion of the phased approach to model development to allow greater freedom for technical discovery.

We believe the recommended phased approach to model development adequately emphasizes the need and importance for documentation to the model development process. We agree with NBS that documentation is an important factor for enhancing the exchange of successful modeling efforts among Federal agencies. However, evidence obtained during the review showed that having documentation procedures did not necessarily insure effective management of the modeling process.

NBS officials stated they are prepared to formulate Government-wide standards pertaining to development of computerized models when resources become available. However, they have not specified when they expect to begin work in this area.

GSA comments

The Acting Administrator of General Services generally agreed that Government-wide standards and guidance should be formulated pertaining to development and procurement of

computerized models. (See app. II.) In addition, he suggested that the management guidance factors presented in the report could be applied to the much broader activity of software development. Our review, however, did not disclose whether the factors could be applied to all software developments, because the factors were developed specifically to deal with problems associated with managing the computer modeling process.

GSA agreed to participate with NBS in the development of Government-wide guidance and standards for development and procurement of computerized models, but did not specify any time frames or specific actions to be taken to complete that task.

Evaluation of proposed actions to be taken

Both NBS and GSA agreed that guidance and standards should be formulated for development of computerized models. However, neither indicated when specific actions would be taken. We believe positive action should be taken on our recommendations by these agencies based on the conditions disclosed in this and in our previous reports. As described on pages 3 and 4 there are millions of dollars involved in this activity and much of this money is wasted. We believe a minor investment by these agencies in the formulation of guidance and standards as recommended in this report could save the Government millions of dollars in model development costs. Also, management of Federal programs could be improved by the better utilization of models that would be more efficiently and effectively developed through use of the guidance and standards.

APPENDIX I

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Administration
Washington, D.C. 20230

September 23, 1975

Mr. Victor L. Lowe
Director, General Government Division
U. S. General Accounting Office
Washington, D. C. 20548

Dear Mr. Lowe:

This is in reply to your letter of August 6, 1975, requesting comments on the draft report entitled "Ways to Improve The Management of Federally Funded Computerized Model Development."

We have reviewed the enclosed comments of the Assistant Secretary for Science and Technology and believe they are responsive to the matters discussed in the report.

Sincerely,

Guy W. Chamberlin, Jr.
Acting Assistant Secretary
for Administration

Enclosure

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AMERICAN REVOLUTION BICENTENNIAL 1776-1976

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Science and Technology
Washington, D.C. 20230

SEP 17 1975

Mr. Victor L. Lowe
Director, General Government Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Lowe:

We have reviewed the draft report to Congress, entitled "Ways to Improve the Management of Federally Funded Computerized Model Development." The document evidences much careful thought and insight concerning a technical area which certainly exhibits a need for an organized management approach.

Careful scrutiny by NBS staff members supports a conclusion that, in general, the GAO-recommended phased approach to model development and the subsequent recommendations for action by the Secretary of Commerce and the Administrator, General Services Administration, are sound and should be formalized. Our reservations are in the nature of changes in emphasis for particular areas, as follows:

(1) Modification of the first two model-development phases, i.e., problem definition and preliminary design, to allow greater freedom for technical discovery.
(2) Amplification of the importance of documentation to the model development process.
(3) Greater emphasis on the voluntary aspects of standards and guidelines.

We are in substantial agreement with the list of useful management steps which make up the five phases, and with the recommendation for separate funding of problem-definition and preliminary-design phases. Early definition of the scope, outputs, and inputs of the model is crucial to successful accomplishment of a modeling project. Definition which is conducted at a very early stage of the modeling process may lead to the discovery of relationships, parameters, and data requirements which are unknown a priori. This process of discovery often results in the identification of new information about a system, and makes the initial phase of a modeling activity justifiable on its own merits, even if further model development is not indicated. Therefore, it is essential that technical specifics which may constrain the creativity of the modeler (for example: "computer language") be more logically fixed at the output of Phase II.

APPENDIX I

Strong documentation specifications and reporting procedures are important both to the model development process itself and to the eventual successful use of the developed product. Mandatory documentation requirements, imposed contractually, together with centralized collection of model abstracts may be vital factors in establishing an effective capability for cross-government model referencing.

Finally, we recommend that adherence to standards and guidelines for model development be kept strictly voluntary, with the exception of certain mandatory documentation and reporting standards. This can ensure effective management of the modeling process while encouraging maximum technical innovation.

The above comments reflect our views on issues of a policy nature. Certain detailed technical questions exist, but these are few and at a level which can be resolved through mutual discussions between our respective technical staffs.

In summary, we do agree with the tenor of the report and we are certainly prepared, under our authority provided by Public Law 89-306 (Brooks Act) and Executive Order 11717, to respond to your specific recommendations that the National Bureau of Standards "formulate Government-wide standards pertaining to the development of computerized models...."

We believe that any program undertaken should result in:

(1) standards for model documentation;
(2) a pilot collection of model documentations with an associated query answering function;
(3) guidelines to support multi-phased model development, procurement, and use.

The resources required for such a program are not provided for under current budgetary submissions. Accordingly, we will commence the program as normal budgetary procedures allow.

Betsy Ancker-Johnson, Ph.D.

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APPENDIX II

UNITED STATES OF AMERICA
GENERAL SERVICES ADMINISTRATION
WASHINGTON, DC 20405

NOV 14 1975

Honorable Elmer B. Staats
Comptroller General of the United States
General Accounting Office
Washington, D.C. 20548

Dear Mr. Staats:

We appreciate the opportunity to review your draft report, "Ways to Improve the Management of Federally Funded Computerized Model Development."

The report contains some representative examples of poor design and management practices in developing simulation models as well as useful management guidelines for future model development and, as such, merits wide exposure to ADP software managers in the Federal Government. The conclusions, however, may be too tightly drawn to the limited subject matter of model development. Actually, the problems indicated are symptomatic of the broader universe of software development and the solutions are not unique to models.

While we generally agree that Government-wide standards and guidance should be formulated pertaining to the development and procurement of computerized models, we suggest that publication of specific procurement guidance be withheld pending the issuance of guidelines to be developed jointly by GSA and the National Bureau of Standards.

If there are any questions, please let us know.

Sincerely,

Dwight Ink

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APPENDIX III

SUMMARY OF QUESTIONNAIRE RESPONSES

TOTAL POPULATION (note a)

	Number of models	Percent of total (note b)
Models by status:		
Development completed and in use	379	73
Development in process	121	23
Development completed but not in use	17	3
Development terminated before completion	2	1
Total	519	100
Models used/developed by type of organization:		
Government contractors	216	42
Civil agencies	122	23
Universities/colleges	79	15
State agencies	47	9
Local agencies	36	7
Defense agencies	19	4
Total	519	100
Models developed by location (States):		
Washington	312	60
Oregon	83	16
Idaho (western)	26	5
Alaska	15	3
Other (outside Seattle region)	83	16
Total	519	100

	Number of models	Percent of total (note b)
Models by purpose:		
Decisionmaking aid	234	45
Basic research	194	37
Decisionmaking aid and basic research	73	14
Decisionmaking aid, basic research, and training	7	1
Basic research and training	6	1
Training	3	1
Decisionmaking aid and training	2	1
Total	519	100
Models by application:		
Science and technology	373	72
Resource allocation	100	19
Transportation	17	3
Economic forecasting	13	3
Inventory	6	1
Economic costing	6	1
Competitive	3	1
Replacement and maintenance	1	0
Total	519	100

APPENDIX III

	Number of models	Percent of total (note b)
Models by functional area:		
Ship construction	58	11
Water resource management	54	10
Weapons research	37	7
Aerospace research	36	7
Transportation and highway planning	34	7
Forestry management	30	6
Water quality	25	5
Fisheries management	22	4
Hydroelectric facilities planning	18	3
Torpedo research	14	3
Production engineering	13	3
Electronic equipment design	12	2
Medical research	12	2
Air quality	11	2
Nuclear waste management	10	2
Thermal powerplant design	10	2
Oceanographic research	9	2
Soil ecosystem research	8	2
Agricultural research	8	2
Community water and sewer design	7	1
Geophysical research	7	1
Econometric forecasting	6	1
Other areas	78	15
Total	519	100

APPENDIX III

	Frequency of problems	Percent of total (note b)
Management problems identified:		
Lack of management planning:		
Difficulty in obtaining data	39	20
Lack of qualified personnel to operate and maintain the model	31	16
Difficulty in translating the problem into specifications for model design	30	15
Inadequate definition of problem	10	5
Other related planning problems	12	6
Subtotal	122	63
Lack of management commitment to use before development:		
Lack of management acceptance and knowledge of modeling techniques	39	20
User not provided with model limitations	6	3
Lack of user participation in planning of the model development	5	3
Management is unaware of what models have already been developed to reduce duplicating the development process	1	0
Subtotal	51	26
Lack of control or coordination of model development:		
Model too complex to be useful	9	5
Lack of management control over the development process	5	3
Lack of documentation as the model is being developed	5	3

APPENDIX III

	Frequency of problems	Percent of total (note b)
Management problems identified (continued):		
Model not validated as it was developed	2	1
Subtotal	21	11
Total	194	100

a/The information was obtained from questionnaire responses received from 538 organizations. It represents general comments and cannot be identified to specific modeling efforts.

b/Some percent figures were rounded so that totals would equal 100 percent.

SUMMARY INFORMATION ON MODEL SAMPLE

Categories	Models by category (note a)			
	Models reviewed		Models with management problems	
	Percent	Total	Percent	Total
Models developed by type of organization:				
Government contractors	56	32	49	16
Universities	19	11	24	8
Civil agencies	23	13	27	9
Defense agencies	2	1	0	0
Total	100	57	100	33
Models by purpose:				
Decisionmaking aid	54	31	52	17
Basic research	18	10	18	6
Decisionmaking aid and research	19	11	21	7
Research and training	5	3	3	1
Decisionmaking aid and training	4	2	6	2
Total	100	57	100	33
Models by application:				
Science and technology	53	30	42	14
Resource allocation	36	21	46	15
Economic forecasting	2	1	3	1
Economic costing	3	2	6	2
Competitive	2	1	0	0
Inventory	2	1	3	1
Transportation	2	1	0	0
Total	100	57	100	33

APPENDIX IV

Categories	Models by category (note a)			
	Models reviewed		Models with management problems	
	Percent	Total	Percent	Total
Models developed by type of functional area:				
Weapons research	23	13	18	6
Water resource management	15	9	25	8
Hydroelectric power management	12	7	12	4
Aerospace research	12	7	6	2
Transportation planning	7	4	9	3
Forest resource management	7	4	9	3
Electronic equipment design	3	2	3	1
Oceanographic research	3	2	0	0
Thermal power research	2	1	3	1
Agricultural research	2	1	3	1
Land use management	2	1	0	0
Fisheries management	2	1	3	1
Law enforcement management	2	1	3	1
Water rescue planning	2	1	3	1
Nuclear power planning	2	1	0	0
Economic forecasting	2	1	3	1
Medical research	2	1	0	0
Total	100	57	100	33
Models by cost:				
$100,000 to $200,000	54	31	55	18
200,001 to 300,000	18	10	18	6
300,001 to 400,000	5	3	6	2
400,001 to 500,000	4	2	3	1
500,001 to 1 million	12	7	12	4
More than 1 million	7	4	6	2
Total	100	57	100	33

APPENDIX IV

Categories	Models by category (note a)			
	Models reviewed		Models with management problems	
	Percent	Total	Percent	Total
Models by source of funding:				
Contract	66	37	67	22
Grant	17	10	15	5
In-house	17	10	18	6
Total	100	57	100	33

a/Some percent figures were rounded so that totals would equal 100 percent.

ORGANIZATIONS THAT PARTICIPATED IN THIS REVIEW

FEDERAL AGENCIES (16)

Agricultural Research Service, Department of Agriculture
Bonneville Power Administration, Department of the Interior
Department of the Air Force
Department of the Army
Department of the Navy
Department of Housing and Urban Development
Department of Transportation
Energy Research and Development Administration
Environmental Protection Agency
Federal Judicial Center
Forest Service, Department of Agriculture
Geological Survey, Department of the Interior
National Aeronautics and Space Administration
National Bureau of Standards, Department of Commerce
National Marine Fisheries Service, Department of Commerce
Office of Water Research and Technology, Department of the Interior

STATE AGENCIES (4)

Washington State Department of Commerce and Economic Development
Washington State Department of Ecology
Washington State Department of Highways
Washington State Department of Natural Resources

LOCAL AGENCIES (3)

Municipality of Metropolitan Seattle (METRO)
Puget Sound Governmental Conference
Seattle Water Department

COLLEGES AND UNIVERSITIES (5)

University of California
University of Idaho
Stanford University
University of Washington
Washington State University

GOVERNMENT CONTRACTORS (12)

Aerophysics Research Corporation
Battelle Memorial Institute (Pacific Northwest Laboratories)
R.W. Beck & Associates
Boeing Corporation
Cornell, Howland, Hayes, Merryfield & Hill
Dynatech R/D Company
Honeywell Marine Systems Division
Oregon Research Institute
Peat, Marwick & Mitchell
Price, Waterhouse & Company
TRW, Incorporated
Water Resources Engineers

PRINCIPAL OFFICIALS

RESPONSIBLE FOR THE ACTIVITIES

DISCUSSED IN THIS REPORT

	Tenure of office	
	From	To
GENERAL SERVICES ADMINISTRATION		
ADMINISTRATOR OF GENERAL SERVICES:		
Jack Eckerd	Oct. 1975	Present
Arthur F. Sampson	June 1973	Oct. 1975
Arthur F. Sampson (acting)	June 1972	June 1973
Rod Kreger (acting)	Jan. 1972	June 1972
Robert L. Kunzig	Mar. 1969	Jan. 1972
Lawson B. Knott, Jr.	Nov. 1964	Feb. 1969
DEPARTMENT OF COMMERCE		
SECRETARY OF COMMERCE:		
Elliot Richardson	Jan. 1976	Present
Rogers C. B. Morton	May 1975	Dec. 1975
John K. Tabor (acting)	Mar. 1975	Apr. 1975
Federick B. Dent	Feb. 1973	Mar. 1975
Peter G. Peterson	Feb. 1972	Feb. 1973
Maurice H. Stans	Jan. 1969	Feb. 1972
C. R. Smith	Mar. 1968	Jan. 1969
Alexander B. Trowbridge	June 1967	Mar. 1968
ASSISTANT SECRETARY FOR SCIENCE AND TECHNOLOGY:		
Betsy Ancker-Johnson	Apr. 1973	Present
Richard O. Simpson (acting)	Aug. 1972	Apr. 1973
James T. Wakelin	Feb. 1971	Aug. 1972
Richard O. Simpson (acting)	Dec. 1970	Feb. 1971
Myron Tribus	Mar. 1969	Nov. 1970
Allen V. Astin (acting)	Feb. 1969	Mar. 1969
John F. Kincaid	Oct. 1967	Feb. 1969