GUIDELINES FOR DOCUMENTING SIMULATION MODELS: A REVIEW AND PROCEDURES

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ABSTRACT: This paper reviews the state-of-the-art of model documentation and summarizes guidelines for preparing documentation for simulation models. The state-of-the-art review summarizes major weaknesses in current model documentation and traces the development of simulation model guidelines that help to alleviate many of those weaknesses. Included are evaluation criteria used to assess the utility of model documentation. A recommended organizational structure is included in the summary of the guidelines for four types of manuals that provide model information to four different classes of audiences (users, analysts, programmers, and managers). In addition, this paper specifies the content of sections and subsections for each type of manual. This paper is based on a more detailed report. [17]

1. INTRODUCTION

Good documentation is crucial for the efficient use of computer software. To promote the development of effective and usable documentation, such groups as the National Bureau of Standards and the Office of the Assistant Secretary of Defense have instituted documentation standards that are required of software developers who support them. [16],[19] While such standards can be applied to all kinds of software, it is generally agreed that certain types of software have unique documentation requirements. Simulation models fall into this category. Many recent articles address the special documentation requirements for computer simulation models. [5],[6],[7],[8],[15] However, few of these articles attempt to provide practical guidelines that can be used to produce adequate documentation. In fact, a primary reason for the inadequacy of much computer simulation documentation is the absence of clear, concise guidelines that provide a checklist and format for preparing such documentation. This paper presents guidelines that have been tested and refined through actual application and review. [14],[17],[18],[20]

The primary purpose of model documentation is to communicate effectively the details of a model's design and operation to persons having varying interests in a model. Since the developers of a model are frequently not the model's ultimate users, complete, concise documentation is essential for the effective use of that model. Documentation should inform analysts, who are familiar with the phenomena being modeled and the modeling techniques being used, of the essential features and assumptions of the model. Throughout its life cycle, a model may be used and modified by numerous people; therefore, accurate and current documentation of the underlying computer program is essential for productive use and maintenance of the model. Ultimately, the results of the model may be used in a decision-making environment by individuals who are unfamiliar with the details of modeling and the associated benefits, risks, and costs. In such situations, model documentation should describe, in non-technical terms, the environment in which a model can be useful, limitations on its use, and the manpower, time, and dollar costs required by its use. To satisfy these diverse needs, this paper presents guidelines for documenting four types of manuals, i.e., the User's Manual, the Programmer's Manual, the Analyst's Manual, and the Management Summary Manual.

The guidelines summary is divided into four major parts, each of which addresses one of the manuals. Each part begins with a short introduction describing the purposes of the particular manual under discussion; presents a prototype table of contents; and describes the specific, recommended contents of the manual. Suggested items may be added to or deleted from the manual, as appropriate.

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These guidelines do not purport to mandate which of these manuals is required, whether the manuals should be prepared as separate volumes, or the like. It is intended that the persons responsible for the documentation of simulation models would decide those issues on a case-by-case basis. Rather, it is intended that these guidelines be used to facilitate the goal of producing simulation model documentation, and thereby, enhance the model's utility.

The early phases of any model development plan should include requirements for basic documentation and documentation maintenance and updates, so that these requirements become part of the development plan rather than an afterthought.

The remainder of this paper is divided into six sections. Section 2 provides a state-of-the-art review of simulation model documentation and reviews the development of the enclosed guidelines. Sections 3 through 6 provide guidelines for preparing specific manual types and Section 7 summarizes the paper.

2. STATE-OF-THE-ART REVIEW

Much has been written recently about the documentation of simulation models, especially about the development of standards and guidelines for documenting simulation models. This section presents a summary of three documentation guidelines already developed, reviews the prevailing attitudes in current literature on model documentation, and provides a case study of the development of successful guidelines for documenting simulation models.

2.1 Guidelines Review

Early attempts to devise procedures for documenting computer software were made by the Department of Defense (DOD) through documentation standards published in 1972 and revised in 1977. [19] The purpose of those standards is to provide guidelines for developing and revising the documentation for computer software throughout the life cycle of a software project. The DOD standards propose using ten different types of manuals, one for each phase of the software's life cycle. While the standards are mandatory for DOD agencies, software managers can use their discretion in determining the number and content of documents according to each manager's needs.

A similar attempt at formulating documentation procedures applicable to all Federal agencies was undertaken by the National Bureau of Standards (NBS). In 1976, the NBS published a set of computer software documentation guidelines in its Federal Information Processing Standards, Publication 38 (FIPS PUB 38). [16] These guidelines are based on the earlier DOD standards and, like the DOD standards, propose ten types of manuals that are associated with ten phases of computer software life cycle. The purpose of the NBS guidelines is to provide a basis for determining the context and extent of computer software documentation. In addition, the NBS guidelines provide a basic reference and checklist for use by all Federal agencies concerned with computer software documentation.

While the DOD standards and the FIPS PUB 38 guidelines apply to all computer software, the Assistant Chief of Staff, Studies and Analyses (AF/SA) has developed guidelines for preparing documentation for specific simulation models used to support military analyses. [18] These guidelines provide methodologies for determining the format and content of User's, Programmer's, and Analyst's Manuals. Included in the guidelines are procedures for ascertaining the number and types of manuals, as well as guidance on when to update documentation.

2.2 Literature Review

Recent articles portray documentation efforts as being only partially successful and as being characterized by incomplete and cumbersome products that fail to enhance model utility. This subsection identifies some of the major documentation problems and offers a solution to those problems. More exhaustive surveys on simulation model documentation are included in references. [5],[6], [7],[15] Since the primary purpose of documentation is to communicate [6], the following discussion relates the effectiveness of model documentation to how well it communicates. Herein, documentation is intended primarily for the use of a third party (i.e., someone other than original user and/or developer of a model).

The primary reason for the inadequacy of much documentation is that documentation is not considered a part of the modeling process and, thus, is not incorporated into the model design and development effort. Nance advances the idea that model documentation should begin at the model design stage and continue throughout the model building, verification, validation, and implementation stages. [15] Gass reinforces this idea by defining documentation as information recorded in all phases of model development. [6] Hayes states that the actual man-hour investment necessary for developing documentation can be minimized by generating documentation concurrent with model development. [10]

Documentation is often inadequate because it fails to address itself to the appropriate audiences. It is not written explicity for programmers who have to convert the model to another computer system. Nor is

it written explicitly for analysts who have to verify mathematical algorithms employed in the model. [5] Effective model communication is enhanced by documentation directed to specific audiences (e.g., users, programmers, analysts, and managers). [17]

Even when documentation is oriented to specific audiences, management quite often is either ignored or presented with useless information. [15] Typically, documentation is addressed only to technical personnel, with the result that little useful information is communicated to the management responsible for initiating a project and/or for using model results in making decisions. [5] Management summaries should provide managers sufficient information to assess accurately the advantages and risks of using a particular model. [17] The discussion should be written in as non-technical terms as possible.

Model documentation typically contains technical terms and/or acronyms peculiar to the system being modeled and/or the language of the model. Such usage can lead to documentation characterized by incomplete, inappropriate, and confused terminology for audiences not attuned to this terminology. [5] Effective documentation avoids the use of specialized terms and programming phraseology and provides a glossary defining all such terms. [17],[18],[20]

Of equal importance to effective documentation is the use of clarifying examples (e.g., figures, tables) to illustrate the narrative. [5] Depending on the complexity of the system being modeled, various levels of block diagrams, etc., should be provided showing the physical system or phenomenon being simulated, as well as diagrams depicting features of the model of that system. [14], [17]

Finally, since complex decision-making models have documentation needs beyond those of complex software systems, a set of guidelines designed specifically for simulation models is needed. [6],[17],[18] These guidelines must facilitate documentation directed toward specific different audiences. The guidelines must summarize a model's weaknesses and strengths in terms understood by management and must make algorithmic details available to analysts, user details available to users, and programming details available to programmers. The guidelines must also be sufficiently flexible to accommodate the specific needs of projects and must apply to all types of simulation models. In other words, simulation model guidelines are needed to prepare documentation that effectively communicates.

2.3 Documentation Guidelines: A Case Study

AF/SA is responsible for the development, maintenance, and use of a wide variety of simulation models. The models range from simple programs that are developed in-house to complex models developed by contractors at the expense of millions of dollars and many man-years of effort. Some models are used infrequently or for single applications; others are used regularly over periods of several years and are disseminated to other Air Force and DOD groups for their use. As part of a concerted effort to make the maintenance and use of the latter category of models more efficient and effective, AF/SA developed a rudimentary set of guidelines for their documentation. [18] The authors became involved in this activity after AF/SA contracted for the development of model documentation for existing, undocumented models, and found the documentation produced by the contractor to be inadequate. The following activities led to the refined version of the AF/SA guidelines that is summarized in Sections 3 through 6.

Documentation Review

The first step in developing the new guidelines was to critique existing documentation prepared using the old guidelines. The basic evaluation approach employed in the documentation critique was to "role-play" new users, analysts, and programmers. A set of evaluation criteria was used to identify major areas in each manual to be reviewed.

Apparent weaknesses and strengths in the documentation were noted when the evaluation criteria were used to organize the review as the roles were played. Activities conducted during the review were as follows:

- Read the documentation for a general understanding
- Critiqued each manual's format
- Studied each manual for a detailed understanding
- Used typical cases for a user and programmer to test the applicability and usability of the documentation
- Subjectively scored each criterion and documented the critiques and recommendations.

A structured list of key manual sections and their attributes was used as evaluation criteria to critique the documentation. Each criterion was used to determine if a particular area has been addressed in such a way that the user of the evaluated manual would benefit. For example, did the tables and figures (or lack of) in the Users's Manual assist in or detract from structuring, running, and analyzing a model experiment?

The manuals were evaluated in five major areas: (1) format, (2) readability, (3) understanding, (4) aplication, and (5) interpretation. Table 2-1 specifies the criteria applied in each area and identifies the manual(s) each criterion was applied against.

In order to summarize the evaluations, a subjective scoring method was applied against the selected criteria. A summary of the criteria scoring for the documentation is presented in the critique. [14] Specific examples and comments on deficient areas are discussed in the critique also.

	MANUAL		
	USERS	PROGRAMMERS	ANALYSTS
FORMAT			
- STRUCTURE	X	X	X
- LOGICAL FLOW	X	X	X
- TABLES/FIGURES USAGE	X	X	X
- APPENDICES USAGE	X	X	X
- EASE OF MAINTENANCE	X	X	X
- SPELLING/GRAMMAR	X	X	X
READABILITY			
- PROPER AUDIENCE	X	X	X
- LOGICAL FLOW	X	X	X
- ADEQUATE CROSS-REFERENCES	X	X	X
- DEFINITION OF TERMINOLOGY	X	X	X
UNDERSTANDING			
- GENERAL OVERVIEW	X	X	X
- METHODOLOGY	X		X
- PROCESSING FLOW		X	
- COMPUTER SPECIFICATIONS		X	
- ASSUMPTIONS/LIMITATIONS	X	X	X
- PROGRAM STRUCTURE		X	
- DATA COLLECTION REQUIREMENTS			X
- INPUT DESCRIPTIONS	X		X
- OUTPUT DESCRIPTIONS	X		X
- RUN INSTRUCTIONS	X		
- ALGORITHMS			X
- DATA ACCURACY	X		X
- DATA FORMATS/VARIABLES	X	X	X
- ROUTINE DESCRIPTIONS		X	
APPLICATION			
- MODEL USAGE	X		
- MODEL MODIFICATION		X	
- MODEL DESIGN			X
INTERPRETATION			
- ANALYSIS OF RESULTS	X		X
- VERIFICATION/MODEL ACCURACY	X	X	X

Table 2-1 Evaluation Criteria

Guidelines Review

Having developed a list of deficiencies in documentation produced according to the original AF/SA guidelines, the next step was to identify areas within the guidelines where improvements could be made that would lead to superior documentation in the future. This step required that documentation deficiencies due to failure of the contractor to follow the guidelines be distinguished from those due to inadequacy of the guidelines themselves.

The original AF/SA guidelines identified three manuals (a User's Manual, Programmer's Manual, Analyst's Manual) to cover the basic documentation requirements for simulation models. Only the User's Manual and Programmer's Manual were mandatory; the Analyst's Manual was optional, depending on the nature of the model being documented. In addition, the guidelines provided for an optional management summary, but provided no guidance as to its contents. The guidelines reviewers concluded that the the three manuals, plus the management summary, could adequately cover the basic documentation requirements for most models. [20] However, there were several areas in which the manuals' organizations could be improved and their content enhanced. It was also concluded that a good management summary was as important as the other three manuals and thus a separate Management Summary Manual was identified and suggestions made for its content.

New Guidelines Development

With the basic results of the guidelines review as a starting point, the original guidelines were completely rewritten with the following objectives in mind with respect to content. The guidelines should

apply specifically to simulation models, be directed to four different classes of audiences, contain a checklist for providing appropriate data on model operation, outline model benefits and restrictions, and provide a glossary of terms that define the technical terms, thereby minimizing the adverse effect of those technical terms. The guidelines should specify the contents of sections and subsections for each type of manual and address specific issues of concern to users, analysts, programmers, and managers interested in using the simulation model. These guidelines were to contain many of the features identified in the Literature Survey (Subsection 2) as being necessary for effective communication.

The new guidelines were produced in an incremental fashion. That is, guidelines for each different manual were developed separately, in draft form, and reviewed with appropriate groups for their comments before they were finalized. For example, draft User's Manual guidelines were reviewed with model users in AF/SA and various contractor organizations. Likewise, draft Analyst's Manual guidelines were reviewed with personnel who were categorized more as analysts than model users (the terms user, analyst, etc., are defined more precisely in later sections). Finally, all four guidelines were consolidated into a single document and released for preliminary use and testing.

New Guidelines Testing and Review

Several large models have been successfully documented using these consolidated guidelines during a one-year testing period. Even though not required, the guidelines are already being used by government and private industry. Feedback from users of the guidelines and recipients of the documentation produced were used, in conjunction with comments from other groups asked to review them, to make final changes before release in final form.

Comments on these guidelines from some reviewers and users are cited below.

"The proposed guidelines for documenting computer simulation models, if adopted, would enhance current procedures for simulation modeling."

"We found the subject document to be comprehensive, readable and full of good information. We particularly liked the numerous examples that brought form and detail to the general concept."

"I think the update of subject guidelines....is quite good and catches the essence of what a users' manual should be."

"We have reviewed the subject guidelines and find the document to be an excellent checklist for the guidance of model-makers in documenting their efforts and for enhancing the utility of a model for analysts and other users who have not participated in its construction."

"We appreciate your guidelines. They provide concrete examples for discussions with our contractors and are of great value."

"...The model documentation guidelines proposed for Analyst's and User's Manuals provide a well-structured format for documenting simulation models. The amount of detail required by the volumes (particularly the Analysts' Manual) should contribute to making models more usable..."

"...Reference to source materials in the Bibliography should be made quite explicit....Nothing is more frustrating than to be given a reference to a 400-500 page textbook when it is clear that only a small-subsection..."

"The theoretical development of the model should include among its assumptions and limitations those factors or features which have been considered but deliberately omitted from the model."

"The discussion on model verification and validation should be strengthened."

"The flow chart descriptions are too detailed."

"Error messages should be listed alphabetically."

3. GUIDELINES FOR PREPARING A USER'S MANUAL

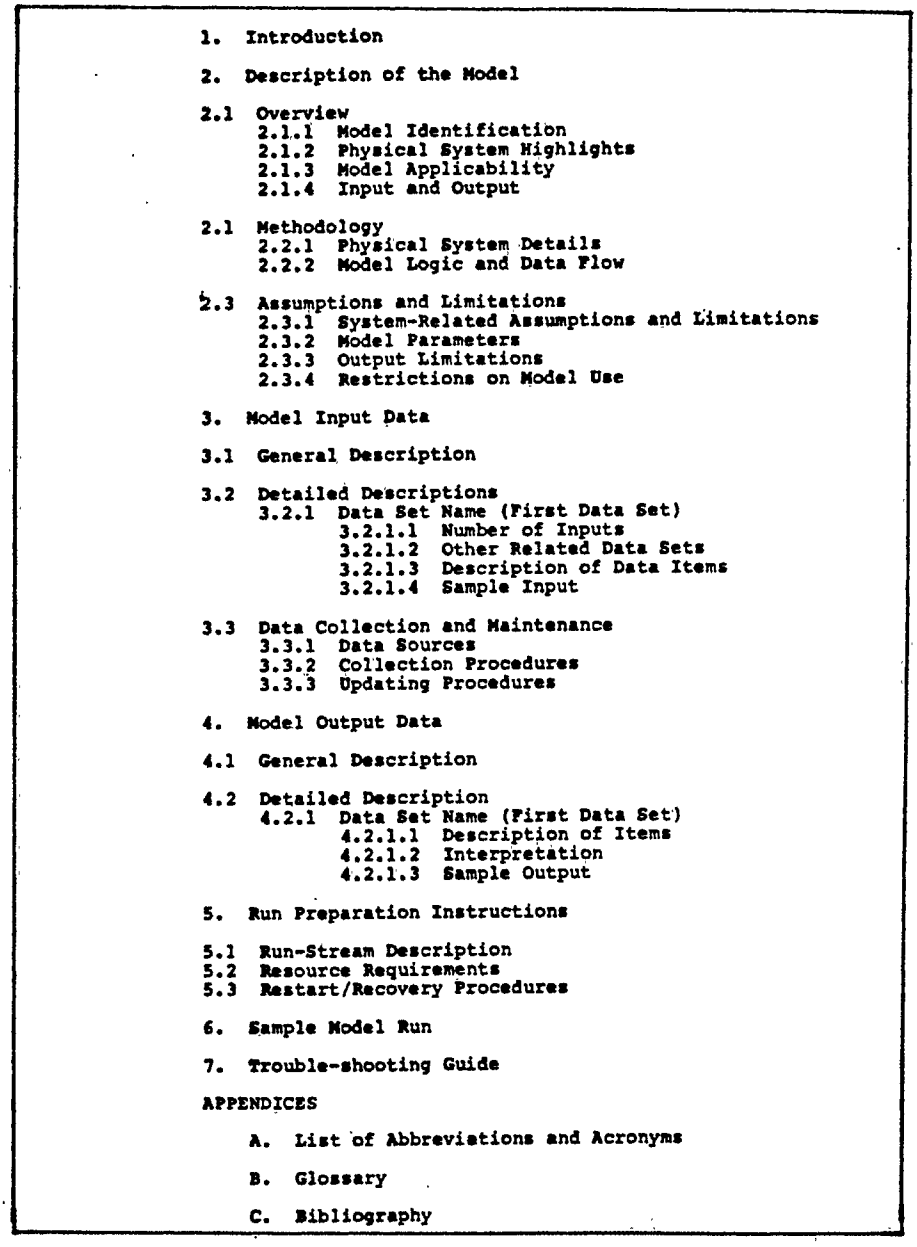
Herein, a user is assumed to be interested mainly in deriving results from a model for specific applications. A user's manual should be organized into sections for the user and sections for the data technicians who will set-up and run the model. To use the model intelligently, a user must be aware of its logical structure, the general simulation approach, and any assumptions and limitations affecting the model's applicability. A user need not be interested in the details of programming or analysis beyond the preparation of input data and the interpretation of model results.

Figure 3-1 presents a recommended table of contents for a User's Manual. The sections and subsections contained in the figure cover the general needs of a user interested in a simulation model. In documenting a particular model, however, additional sections and subsections may be added to improve clarity, while some subsections may be omitted for simple models. Note that there is a certain amount of redundancy among the various sections of a User's Manual prepared according to these guidelines. Nevertheless, the progressively increasing level of detail dictated by this structure is desirable to satisfy different levels of user interest in the manual. The remainder of this part of the guidelines comprises a discussion of the contents for the eight recommended sections.

3.1 Introduction

The introduction to a User's Manual should contain the background of the project, the purpose of the simulation model, and an overview of the remaining sections in the manual. A common introduction may be used for all the manuals prepared for a simulation model, but the specific purpose of the User's Manual should be included in a statement of the form:

> "The purpose of this manual is to provide nonprogramming users of (model name) with the information necessary to use the model effectively."



1. Introduction

2. Description of the Model

2.1 Overview
- 2.1.1 Model Identification
- 2.1.2 Physical System Highlights
- 2.1.3 Model Applicability
- 2.1.4 Input and Output

2.1 Methodology
- 2.2.1 Physical System Details
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2.3 Assumptions and Limitations
- 2.3.1 System-Related Assumptions and Limitations
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- 2.3.3 Output Limitations
- 2.3.4 Restrictions on Model Use

3. Model Input Data

3.1 General Description

3.2 Detailed Descriptions
- 3.2.1 Data Set Name (First Data Set)
  - 3.2.1.1 Number of Inputs
  - 3.2.1.2 Other Related Data Sets
  - 3.2.1.3 Description of Data Items
  - 3.2.1.4 Sample Input

3.3 Data Collection and Maintenance
- 3.3.1 Data Sources
- 3.3.2 Collection Procedures
- 3.3.3 Updating Procedures

4. Model Output Data

4.1 General Description

4.2 Detailed Description
- 4.2.1 Data Set Name (First Data Set)
  - 4.2.1.1 Description of Items
  - 4.2.1.2 Interpretation
  - 4.2.1.3 Sample Output

5. Run Preparation Instructions

5.1 Run-Stream Description
5.2 Resource Requirements
5.3 Restart/Recovery Procedures

6. Sample Model Run

7. Trouble-shooting Guide

APPENDICES

A. List of Abbreviations and Acronyms

B. Glossary

C. Bibliography

Figure 3-1 Recommended Table of Contents for a User's Manual

3.2 Description of the Model

This section should contain a well-structured presentation of the logical details of the model. The material here should be descriptive and should include block diagrams, tables, and charts where needed. This section of the User's Manual should not give details needed by a data technician to run the model.

Overview

This subsection should provide sufficient general information about the model to assist a user in determining the applicability of the model for his specific needs. Subsections that address the following areas should be included: (1) identification of the physical system modeled, programming languages in which the model is written, and the computer on which the model runs; (2) a discussion of the physical system being modeled; (3) a discussion on the general magnitude of model applicability; (4) a general statement of the classes of model input data and results; and (5) any special data collection procedures.

Methodology

This subsection should provide the user with a detailed understanding of how the model works. Subsections that provide details on (1) physical system components and their interactions and (2) the logical flow of data through the model should be included.

Assumptions and Limitations

All the system-related assumptions, assumptions on model parameters (e.g., hard-coded values), limitations on output accuracy, and any restrictions on the use of the model should be discussed in detail. Include those features that were considered but were deliberately excluded from the model.

3.3 Model Input Data

This section should describe in detail all the input data needed to run the model. The material in this and the four subsequent sections should serve as a reference for both the user and the data technician who runs the simulation model.

General Description

This subsection should describe the overall input data structure and the data media (tape, cards, disk data sets, etc.). Include a table that shows input data set names, their media, and any general data limitations. Also, describe the interdependence, if any, of input data sets. (Detailed descriptions of individual data items within the input data sets should be left for the next subsection.)

Detailed Descriptions

Input data items are normally organized in related groups, such as aircraft characteristics, missile characteristics, etc., or as the data items that are entered on one punch card. These related groups of data establish and define a data set and should be described together. The input data sets and the items within each data set should be discussed in the order of their appearance in the run stream. For each input data set, provide the following information (each data set description should begin on a new page): (1) name of data set, (2) identification of the number of inputs, (3) related data sets, (4) description of format, and (5) sample input.

Data Collection and Maintenance

An important part of simulation model application is data collection. Therefore, it is necessary to include appropriate instructions on data collection and maintenance, as follows:

(1) identify the form in which raw data are available, other organizational elements from which the data must be collected, if appropriate, and the time required to collect the data;

(2) describe any special statistical techniques or experiments for obtaining the data, identify any other computer programs or models that must be used to collect or process data, and list or reference instructions for their use;

(3) give step-by-step procedures for maintaining the data sets and for preparing new experiments.

3.4 Model Output Data

This section should describe in detail all the output data produced by the model and should indicate their meanings and uses.

General Description

Discuss the overall output structure in this subsection. Indicate the number and types of output data sets, output media, correlation between outputs, quantity of output (optional and mandatory), and post-processing, if any, that should be performed on the output data.

Detailed Description

For each output data set (or major group of logically connected data items), include information that (1) identifies the data name, (2) provides a brief description of each item in that data set, (3) describes how that item is used, and (4) depicts a sample of each output data set.

3.5 Run Preparation Instructions

This section of the User's Manual should describe procedures for organizing the input data to submit computer runs, as discussed in Section 3.

Run-Stream Description
This subsection should give a graphic representation of the deck constituting the run-stream that shows all the control cards (JCL) and the data cards in proper sequence. Mandatory and optional cards should be discussed. If the model is interactive, include comments on any special techniques used for interactive submission (e.g., TSO) of jobs.

Resource Requirements
This subsection should describe the computer resources required by the simulation model. These include main memory, mass storage, number of tape units, execution time, numbers of punched cards, and printed lines expected as output. If the computer resources vary depending on input data, provide aids to estimate them.

Restart/Recovery Procedures
For models that require large amounts of computer resources, it is important to recover from abnormal terminations and to restart the job. If any such provisions are made in the model design, they should be discussed in this subsection.

3.6 Sample Model Run

Include a sample run that illustrates the complete input scenario and the resulting output to assist a beginning user in making a test run and in verifying the correctness of procedures.

3.7 Trouble-Shooting Guide

Tabulate user input error-messages produced by the software, and describe the required corrective action. Since other errors should be handled by programmers, those errors should be discussed in the Programmer's Manual.

3.8 Appendices

Three appendices should be provided as required. Appendix A should provide an alphabetical listing of all abbreviations and acronyms appearing in the User's Manual. Appendix B should list and define all specialized terms used. All applicable documents, including cited and uncited references, should be provided in Appendix C. References should include the page numbers that contain the referenced data when only a small subsection of the text is involved.

4. GUIDELINES FOR PREPARING A PROGRAMMER'S MANUAL

Herein, programmers are viewed as being interested primarily in maintaining and modifying a model. A programmer must correct all errors discovered during model usage that are are not attributable to user-entered data. Programmers, especially those required to convert a model to another computer system, need to understand the features of a model that are installation unique. Thus, a Programmer's Manual must provide all the details necessary to understand the operation of a model, to trace through a model to debug it, to make modifications, and/or to convert the model to other computer systems.

Figure 4-1 is a recommended table of contents for a Programmer's Manual. The sections and subsections included in the figure cover the general needs of a programmer interested in a simulation model. In documenting a particular model, however, additional sections and subsections may be added to improve clarity, while some subsections may be omitted for simple models. If appropriate, documentation produced using programming conventions should be used in preparing the Programmer's Manual. The remainder of this part of the guidelines comprises a discussion of the contents for the eight recommended sections for a Programmer's Manual.

4.1 Introduction

The introduction to the Programmer's Manual should contain the background of the project, the purpose of the simulation model, and an overview of the remaining sections in the manual. A common introduction may be used for all the manuals prepared for a simulation model, but the specific purpose of a Programmer's Manual should be included in a statement of the form:

> "The purpose of this manual is to provide programmer personnel of (model name) with the information necessary to effectively maintain and modify the model."

Figure 4-1 Recommended Table of Contents for a Programmer's Manual

4.2 Model Specifications

This section of the Programmer's Manual should provide a summary of the model's specifications and capabilities (i.e., problems addressed and methods of solution), a description of the host computer system, and the processing requirements (i.e., memory, peripherals, languages) placed by the model on that host system. The details should be presented in tabular form (supplemented by narrative description, as appropriate), whereby one table describes the complete modeling system and additional tables describe major submodels and/or programs, as needed for clarity.

4.3 Model Description

This section should contain a well-structured presentation of model details with emphasis on the operational details of the model. The discussion should be written in an easy-to-understand manner that cross-references special model language terms with modeled system features whenever possible. This section should be divided into four subsections.

Processing

This subsection should provide details on model operations for programmers who need to understand the processing techniques used in the model. The discussion should be at the "Macro" level, with a discussion of internal routine details postponed until Section 4 of this manual. Details on I/O formats and default

input data values should be reserved for the User's Manual. Block diagrams should be used as necessary to supplement the narrative. Subsections should provide the following: (1) an overview of the problem solved by the model; (2) a description of the flow of data and/or control information through the model at the major routine, or routine group, level; (3) the identification of any differences between the performance of model tasks accomplished during model initialization and wrap-up and the performance of those same tasks when performed during normal processing.

Data Structures
This subsection should provide information on all data structures internal to the model. Include descriptions of local and global variables, arrays, and data sets, as well as any special data structures, such as the set-entity relationships in SIMSCRIPT. If required for understanding, separate descriptions of each array index should be provided. Subsections should be included that provide (1) the meaning and purpose of all local variables, arrays, and data sets (local data structures have their values defined only within particular routines); (2) the meaning and purpose of all global variables, arrays, and data sets (global data structures are defined throughout the model); and (3) any special data structures, both local and global, used in the model.

Overlays
If the model is overlayed, this subsection should provide details of the overlay design decisions that determined the overlay strategy. Included should be a narrative and a block diagram description of the control flow of the overlays and their interactions. Routines residing in each overlay, and their memory requirements, should be listed. References should be made to the discussion of model processing in this manual to reinforce or clarify the overlay discussion.

Model Modifications
This subsection should include information concerning changes in model software and data bases. Include a description of any programming conventions used in the model (e.g., all variables referencing one data base may begin with a specific character). In addition, this subsection should provide procedures needed by programmers during the model compilation, recompilation, and execution stages. Include a sample control card (JCL) setup that illustrates each of those states, including mandatory and optional cards. If the model is interactive, include comments on interactive procedures. As appropriate, provide details on (1) all planned periodic maintenance on the model and its data bases (e.g., periodic data base updates) and (2) procedures for making all modifications to the model other than planned periodic maintenance.

4.4 Description of Routines

This section should provide a detailed description of principal model routines. Include a discussion of all types of routines that comprise the model (i.e., event, subroutine, function, etc.). Provide an alphabetized listing of all routine names, calling routines and called routines, and/or a block diagram showing routine linkages, as needed. Each routine should be described in a separate subsection. For each routine, provide the following information:

- routine name
- briefly state the purpose of the routine (e.g., computes rates at which elements enroute to a base arrive at the base)
- specify the type of routine (i.e., function, subroutine)
- list all variables, arrays, pointers in the routine calling sequence
- define all routine arguments
- list all routines that call this routine
- list all routines called by this routine
- list all files this routine creates or uses
- itemize all errors detected in this routine
- include a narrative description, as necessary, to amplify the code and highlight subleties included in the code
- use block diagrams and/or other documentation aides (such as program documentation languages), as required to depict clearly the operation of the routine
- provide the results of test runs, along with values of input data, for each complex routine to assist in verifying changes to those routines

4.5 Data Base Description

This section should discuss all mass storage files used or created by the model. Each file should be described in a separate subsection and on a separate page. The description should identify (1) the file name, (2) the purpose and format of the file, (3) the routines that build or use that file, and (4) the file maintenance and update procedures, including actual programming instructions for that file.

4.6 Source Listing

This section should contain the source code of the model. If the source listing is large, it should be bound separately and made available upon request. Also, source listings with line numbers can be referenced from Subsection 3.2 of this part of the guidelines as a cross-reference for model variables, as appropriate.

4.7 Error Messages

All program-generated error messages and the names of the routines in which they are generated should be listed in this section. Each error message may be described in a separate subsection.

4.8 Appendices

Four appendices to this manual should be provided as required. Appendix A should define all terms not defined elsewhere in the document. A list of applicable documents, including cited and uncited references, should be provided in Appendix B. Appendix C should provide an alphabetized index that gives the page on which each subject in the Manual may be found. If the Programmer's Manual is divided into more than one volume, the index in the first volume should be the index to all volumes. The index in each of the remaining volumes should reference only those subjects within that volume. Appendix D should provide a listing of model test results, along with values entered into the model that produced those results. Include any interim model outputs necessary to understand the final outputs. Provide analyses of model results, as necessary.

5. GUIDELINES FOR PREPARING AN ANALYST'S MANUAL

Herein an analyst is assumed to be interested primarily in the analytical techniques and algorithms used in a model. Specifically, an analyst is concerned with the equations used in a model and the methods used for model verification and validation. An analyst does not need to know user details such as input and output formats, or programming details involving language syntax. Further, if the modeling effort is dominated by programming aspects and no new or complicated analytical concepts are involved, an Analyst's Manual may not be necessary.

Figure 5-1 contains a recommended table of contents for an Analyst's Manual. The sections and subsections included cover the general needs of an analyst interested in a simulation model. In documenting a particular model, however, additional sections and subsections may be added to improve clarity, while some subsections may be omitted for simple models.

5.1 Introduction

The introduction to the Analyst's Manual should contain the background of the project, the purpose of the simulation model, and an overview of the remaining sections in the manual. A common introduction may be used for all the manuals prepared for a simulation model, but the specific purpose of the Analyst's Manual should be included in a statement of the form:

> "The purpose of this manual is to provide nonprogramming analysts of (model name) with the details of the algorithms used in the model and the techniques employed for model verification and validation."

5.2 Functional Description of the Model

This section of the Analyst's Manual should contain a well-structured presentation of the functional details of the model. The discussion should be written in an easy-to-understand manner that, whenever possible, avoids the use of highly specialized terms. The section should be divided into four subsections.

Overview

This subsection should provide a functional description of the model in sufficient detail for an analyst to understand the salient system features modeled. Functional flow charts and other graphics should be used to enhance the narrative. Include a statement of the kind of model simulated (e.g., fixed-time increment simulation model that simulates the air missions of two forces whose tactical aircraft not only attack airfields but also provide ground forces support) and the degree to which the model portrays the real world system. Included should be the set of model responses (output) produced by a given set of model input data. For additional details on model description, the analyst should be directed to the appropriate section of the User's Manual for this model.

Detailed Methodology

This subsection should provide the functional details for analysts to understand the algorithms and equations used in the model. Well-known mathematical equations (and formulae) should be clearly identified and references should be cited for their derivation. In a war game model, an example of an algorithm that could be included is the description of procedures, including equations, used for calculating impact points. Include the derivation for extensions of known results or for the development of new analytical techniques. Special complicating details, such as the use of precalculated data for expected kill rates, should be noted. The description must be detailed enough to demonstrate how the model uses the input data to calculate output information. Functional flow charts and graphs should be used to enhance the narrative descriptions of each algorithm. This section should include a subsection for each major algorithm or set of equations.

Figure 5-1 Recommended Table of Contents for an Analyst's Manual

Assumptions and Limitations
This subsection should list all model assumptions and all factors that affect or limit model output use. The discussion should (1) itemize all stochastic assumptions that affect model output accuracy, (2) include all limitations on the size of the problem the model can address, and (3) identify critical input data values to which model results are sensitive.

Model Flexibility
This subsection should address the capability of adapting the model to changing requirements, such as anticipated physical system operational changes, interaction with new or improved models, and planned periodic changes. An example of a flexible design is one that facilitates the addition of a munitions defense action to a war game model at a later date. Model components and procedures designed to be flexible must be clearly identified. Factors that affect model flexibility are the familarity of the analyst with the model, the model's size, its complexity, and its data structures. Subsections should be used as required.

5.3 Model Input and Output Data

This section should discuss the categories of input data and the accuracy of model output data. The material contained in the next two subsections will enable the analyst to assure the existance of the data necessary to execute the model and to ascertain the accuracy of the data generated by the model.

Input Data
Identify all categories of input data and any special analytical techniques required to obtain those data. If the sources of input data include output from other models, provide sufficient details to enable an analyst to assess the appropriateness of those data in solving the problem. For example, if the expected kill rates of a particular type of aircraft are provided by another model, the analyst needs to ensure that those data apply to the type of aircraft in this model. Details on input data types and formats should be reserved for the User's Manual.

Output Data
This subsection should provide the analyst with a methodology for assessing the accuracy of model output data. Since the accuracy of the output values will be judged in relation to the method used to derive them, a review of the algorithms used to compute those output values may be necessary at this point.

Describe in detail any corrective actions to be taken by an analyst in case of inaccurate output values (i.e., should the analyst either contact a programmer for a program change or have a user modify the input data deck to correct the problem?). Subsections may be used as required.

5.4 Model Verification and Validation

This section of the Analyst's Manual should describe the methodology used to verify and validate the model. Model verification (sometimes referred to as software validation) is concerned with the compatibility of the model's programmed structure to the analyst's design and with model debugging. Model validation provides the analyst and user with the confidence that the model is a good representation of the modeled system.

Verification Techniques
This subsection should provide an analyst with concise procedures used to verify the model. Each equation included in Subsection 5.2 of the Analyst's Manual should be verified and cross-referenced to the Programmer's Manual for this model. Include all other verification techniques used.

Validation Considerations
This subsection should provide an analyst with the description of any procedures that were used to ensure that the model is an "accurate" abstraction of the real system. Any methodology used to determine how well the model represents the real system should be presented in this section. While complete confidence in a model may be impossible, a good validation procedure can increase the amount of confidence an analyst has in a model.

5.5 Appendices

Two appendices should be provided as required. Appendix A should define all specialized terms in the Analyst's Manual. Appendix B should list all applicable documents, including cited and uncited references.

6. GUIDELINES FOR PREPARING A MANAGEMENT SUMMARY MANUAL

Models are used chiefly in a decision-making environment. Thus, the main goal of a Management Summary Manual is to assist managers in making decisions. To accomplish this, a Management Summary Manual must describe the model and its application to managers (including the management that sponsored the model) who may be interested in using a developed capability. A Management Summary Manual should provide managers with sufficient information to assess accurately model input requirements (including time and money), available outputs, and the accuracy and precision of the results. Managers can use the Management Summary Manual in justifying the employment of the model and in evaluating subsequent results.

Figure 6-1 is a recommended table of contents for preparing a Management Summary Manual. The sections and subsections included in that figure list suggested topics that are of interest to managers. Items may be added to or deleted from this table of contents, however, according to individual requirements.

6.1 Introduction

The introduction to the Management Summary Manual should identify the sponsoring organization, provide the background of the project, state the purpose of the simulation model, and present an overview of the remaining sections in the manual. A common introduction used for other manuals prepared for a simulation model may be used only if that introduction is void of specialized terms. The specific purpose of the Management Summary Manual should be included in the introduction in a statement of the form:

> "The purpose of this manual is to communicate to management the capabilities and limitations of (model name)."

6.2 Model Description

This section of the Management Summary Manual should provide a summary of model capabilities and limitations. Use high-level block diagrams to clarify the narrative, as needed.

Capabilities
This subsection should briefly summarize the capabilities of the model. Include highlights of mathematical and engineering concepts (but not equations) used as the basis of the model. Include a statement of the model's primary purpose. For example, the model might be used to study the daily number of bomber missions required to keep enemy resupply capabilities below a certain level. Provide an overview of functional details that explains how the model accomplishes its stated purpose. Discuss the general areas of the model's applicability. For example, describe the types of systems and situations that can be simulated by the model (possibly with minor changes), including the number and kinds of subsystems (e.g., aircraft in a war game simulation) that can be simulated. Also, include the relationship of this model to any other model (i.e., another model may prepare input data for this model).

Figure 6-1 Recommended Table of Contents for a Management Summary Manual

Input/Output Description
Provide a short discussion on the different classes of input data required to drive the model and of output data generated by the model. For example, a war game model might require entry of the number and disposition of enemy troop units, enemy resupply capabilities, the characteristics and location of friendly bombers, and hit probabilities of different bomb types. An example of model output might be statistics that show the reduction in enemy resupply capabilities due to friendly bomber missions. Identify any special preprocessing required for input data, as well as all post-processing required for model results.

Assumptions and Limitations
List any assumptions in the model that limit the applicability of the model. Identify any restrictions on model usage caused by accuracy limitations of input parameters and output data. Provide comments on levels of detail in the model that affect the model's applicability. For example, an analytical representation, rather than a detailed simulation, of a system component could affect model application. Also describe any use of random parameters that may affect the accuracy and use of model output.

6.3 Model Development and Experimentation

This section should describe significant model experiments already run and should provide details on model verification and validation procedures used. Include information on the model's development history and resource costs and requirements.

Development History
This subsection should provide pertinent details of the history of model development. Include comments on any alternative methods to computer simulation that were considered. Provide information on any "lessons learned" during model development, such as cost overruns, model development delays, user dissatisfaction with model results, insufficient workload data to support current and future model applications, inadequate model documentation, poorly defined problems, etc.

Verification/Validation
This subsection should describe any verification and validation procedures performed on the model. Include any analyses performed on the sensitivity of model output data to variations in model input data.

Model Experiments
Describe significant model experiments performed and their results. Briefly describe the purpose of each experiment and the extent to which each experiment's goals were realized. Discuss the management decisions affected by each experiment. Discussion of major model experiments may be included in separate subsections.

Costs and Resource Requirements
This subsection should provide details on the costs and resource requirements of the model. Include the cost (in time and money) of collecting and validating input data. For example, long and costly data collection efforts may be necessary. Provide comments on model maintenance and experiment costs. Summarize model specifications by graphs and narrative descriptions, as appropriate. Discuss job turnaround times (including typical run times) and peculiar model requirements such as abnormally large core requirements or long run times. Include comments on model portability, proprietary considerations, and security requirements, as needed.

6.4 Current and Additional Applications

This section should summarize benefits already derived from the model and recommend any other applications for the model.

Current Use
This subsection should briefly describe how the model has been used by management in its decision-making process. Provide details of recommendations and conclusions derived using the model.

Additional Applications
This subsection should provide details of any additional applications and uses of the model beyond the current usage. Discuss in general terms any extensions and enhancements to the model which are feasible and could improve its utility. Identify any extensions which have been scheduled or planned.

6.5 Appendices

Two appendices should be provided as required. Appendix A should reference all other project documentation (including the User's Manual, Analyst's Manual, and Programmer's Manual), and should reference the organization and person(s) responsible for maintaining the document. Include references to any documentation of experiments performed using the model. Appendix B should list all applicable documents (excluding project documentation previously included in Appendix A), as well as cited and uncited references.

7. SUMMARY

This paper has presented a review of the state-of-the-art of simulation model documentation. Included are a review of current procedures for preparing model documentation, a review of existing model documentation, a documentation case study, and a summary of successful guidelines for preparing model documentation. The primary emphasis of the paper is on the various aspects of simulation model guidelines that have been tested through actual application and review.

The paper advances the case for unique guidelines for preparing simulation model documentation that are different from guidelines for preparing general computer software documentation. This idea is reinforced by the NBS' decision to fund further refinement to the guidelines described herein for subsequent release as an NBS technical publication.

Herein, the primary purpose of model documentation is depicted as the communication of model design and operations details to person's having varying interests in a model. Thus, the guidelines propose four types of manuals, i.e., User's Manuals, Analyst's Manuals, Programmer's Manuals, and Management Summary Manuals.

Though all the ideas presented herein are important, effective documentation cannot be obtained without management support. Management's attitude toward the documentation effort and the enthusiasm with which it is approached will go far toward making the documentation effort, and consequently the complete modeling project, a successful undertaking.

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