

*Wheight*

# NATIONAL BUREAU OF STANDARDS REPORT

10 430

A SEARCH AND RESCUE SIMULATION MODEL FOR THE UNITED STATES COAST GUARD

VOLUME I

EXECUTIVE LEVEL DOCUMENTATION

Sponsored by  
U. S. Coast Guard



U.S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS

## NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards<sup>1</sup> was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

**THE INSTITUTE FOR BASIC STANDARDS** provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Measurement Services and the following technical divisions:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics<sup>2</sup>—Radio Engineering<sup>2</sup>—Time and Frequency<sup>2</sup>—Astrophysics<sup>2</sup>—Cryogenics.<sup>2</sup>

**THE INSTITUTE FOR MATERIALS RESEARCH** conducts materials research leading to improved methods of measurement standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Physical Chemistry.

**THE INSTITUTE FOR APPLIED TECHNOLOGY** provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations in the development of technological standards, and test methodologies; and provides advisory and research services for Federal, state, and local government agencies. The Institute consists of the following technical divisions and offices:

Engineering Standards—Weights and Measures—Invention and Innovation—Vehicle Systems Research—Product Evaluation—Building Research—Instrument Shops—Measurement Engineering—Electronic Technology—Technical Analysis.

**THE CENTER FOR RADIATION RESEARCH** engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center consists of the following divisions:

Reactor Radiation—Linac Radiation—Nuclear Radiation—Applied Radiation.

**THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY** conducts research and provides technical services designed to aid Government agencies in the selection, acquisition, and effective use of automatic data processing equipment; and serves as the principal focus for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information—Computer Services—Systems Development—Information Processing Technology.

**THE OFFICE FOR INFORMATION PROGRAMS** promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System, and provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information<sup>3</sup>—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

<sup>1</sup> Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

<sup>2</sup> Located at Boulder, Colorado 80302.

<sup>3</sup> Located at 5285 Port Royal Road, Springfield, Virginia 22151.

# NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

4314561

June 18, 1971

NBS REPORT

10 430

A SEARCH AND RESCUE SIMULATION MODEL FOR THE UNITED STATES COAST GUARD

VOLUME I

## EXECUTIVE LEVEL DOCUMENTATION

by  
R. T. Penn, Jr., W. G. Leight

Sponsored by  
U. S. Coast Guard

### IMPORTANT NOTICE

NATIONAL BUREAU OF STANDARDS  
for use within the Government. Be  
and review. For this reason, the p  
whole or in part, is not authorize  
Bureau of Standards, Washington,  
the Report has been specifically pr

Approved for public release by the  
director of the National Institute of  
Standards and Technology (NIST)  
on October 9, 2015

accounting documents intended  
jected to additional evaluation  
ting of this Report, either in  
office of the Director, National  
he Government agency for which  
es for its own use.



U.S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS



A Search and Rescue Simulation Model for the US Coast Guard  
Executive Level Documentation

TABLE OF CONTENTS

	page
Preface. . . . .	i
Abstract . . . . .	iii
Introduction . . . . .	1
Classes of Problems and Decision Tools . . . . .	2
The Search and Rescue Model. . . . .	3
An Overview of SARSIM. . . . .	5
The Preprocessor (PREPRO). . . . .	8
The Operational Simulation (OPSIM) . . . . .	9
The PostProcessor (POSTPRO). . . . .	13
Credibility of the Simulation Model. . . . .	13
General Examples of the Use of SARSIM. . . . .	14
Concluding Remarks . . . . .	17
A Sample Simulation of a Simple SAR Situation. . . . .	Appendix A



## PREFACE

This volume is one of a series which documents a Search and Rescue Simulation Model for the United States Coast Guard. The material reported in this documentation was developed by an interdisciplinary team at the National Bureau of Standards with representation from the U.S. Coast Guard under MIPR Z-70099-0-01935.

The complete documentation is comprised of the following:

Volume I     Executive Level Documentation

Volume II    Analyst Level Documentation

Volume III   Programmer Level Documentation for "PREPROCESSOR"

Volume IV    Programmer Level Documentation for "OPSIM"

Volume V     Programmer Level Documentation for "POSTPROCESSOR"

Appendix A   Flow Charts for Programmer Level Documentation

Appendix B   Program Listings for Programmer Level Documentation

The study was initially conducted under the supervision of Martin J. Aronoff; subsequently efforts were supervised by Richard T. Penn, Jr. Technical Project Leadership was supplied throughout the project by Stephen S. Karp. Other participants from the National Bureau of Standards Technical Analysis Division included the following:

Susan S. Chamberlin

Elizabeth E. Leyendecker

Linda K. Cummings

Marcia D. Maltese

Mary Jane Duberg

Patsy L.B. Saunders\*

William Elliott, III

Wayne A. Steele

Walter G. Leight

Michael R. Vogt

Joel Levy

Arnold L. Weber



Valuable advice was received from Alan J. Goldman\* and Prof. Gustave J. Rath of Northwestern University.

U.S. Coast Guard participants included:

Paul D'Zmura

Gerald L. Underwood

Thomas T. Matteson

Robert R. Wells

Support services were furnished by the following members of the  
NBS Technical Analysis Division:

Mary M. Abbott

Frances E. Jones

Theresa I. Conrad

Lucinda I. Farrell

\* Staff members of the NBS Applied Mathematics Division



# A Search and Rescue Simulation Model for the U.S. Coast Guard

## Executive Level Documentation

### ABSTRACT

An inter-disciplinary team, comprised of members of the staff of the Technical Analysis Division of the Bureau of Standards and representatives of the U.S. Coast Guard, has developed a Search and Rescue Simulation Model (SARSIM). Actual or projected values are used for such parameters as location of Coast Guard stations; types, deployments and capabilities of resources; manning levels; case loads; and resource assignment policies. Computer runs of the model can then provide rapid and realistic simulations of the Search and Rescue (SAR) process, supplying as output appraisals of the degree to which satisfactory service is provided, utilization of individual resources and resource types, average length of time for cases awaiting service, etc. SARSIM thus represents a powerful managerial tool with which Coast Guard planners and decision makers can economically and expeditiously explore the likely effects of proposed major changes in allocation or mode of operation.



## INTRODUCTION

The United States Coast Guard has been tasked, under law, to provide Search and Rescue (SAR) services to people and property in peril on the high seas or in waters subject to the jurisdiction of the United States. Towards fulfilling this mission, approximately \$150 million is budgeted annually for 12,000 Coast Guardsmen to operate 2734 vehicles of 45 different kinds (i.e., boats of various sizes, cutters, fixed-wing aircraft and helicopters) at 285 stations along the Atlantic, Pacific and Gulf Coasts of the continental United States, Alaska, Hawaii and the South Pacific and such inland waterways as the Mississippi River and the Great Lakes.

The management of such a large and far-flung enterprise is clearly a major undertaking, particularly when consideration must continually be given to significant changes in:

- (a) funding
- (b) manning levels
- (c) operating costs
- (d) procurement of replacement equipment or ordering of newly-developed devices or vehicles
- or (e) demands for services, which may go up with increases in recreational boating or go down as a result of successful safety programs.

The managerial problems referred to above are many and varied; the approaches proposed to solve these problems may be even more

numerous. The purpose of this paper is to describe an analytical tool designed to assist Coast Guard decision makers in their explorations and comparisons of the relative effects of various changes under consideration.

#### CLASSES OF PROBLEMS AND DECISION TOOLS

Management problems concerned with SAR are, in essence, involved with allocation of limited resources with the goal of achieving desired levels and standard of service. Thus, by way of examples, decisions may be required with regard to:

- (a) establishment, relocation or disestablishment of shore stations or air stations within a Coast Guard district;
- (b) changes in manning levels at individual stations or throughout a district;
- (c) relocation of resources from one station to another or other changes in the relative mix or availability of different kinds of resources;
- (d) introduction of new types of resources, either as replacements for or in addition to existing resources;
- or (e) decisions whether action should be taken in anticipation of radical changes in demands for services.

Selection of a course of action can, of course, be made in the traditional fashion of utilizing individual judgment based on experience and expert opinion. In some situations it may be possible to experiment with changes in policy or equipment, but empirical trials in actual

situations are often time-consuming and costly, and often entail risk. Another alternative involves modeling and analyzing the operation and in estimating the likely outcome of the proposed courses of action. In any event, the results of experiment or of analysis are presented to the decision-maker for his consideration along with any other inputs.

A theoretical model, by its nature, is an abstraction from reality: it is an attempt to represent a complex process in sufficiently simple, idealized fashion that it can be manipulated readily and with maximum possible flexibility. At the same time, it must mirror the real world with adequate faithfulness in its critical elements so that results from the model will be accepted as applying in the real world. Such models, when successfully designed, can be exercised at relatively low cost and minimal risk, producing objective results, generally of a quantitative nature.

#### THE SEARCH AND RESCUE MODEL

The theoretical model of the search and rescue mission, which underlies the simulation model (SARSIM) described in the following section, was developed by an interdisciplinary team of analysts and programmers of the NBS Technical Analysis Division with the active cooperation and participation of representatives of the Coast Guard. As a result, it is considered that the analytical model is a reasonable and valid representation of the search and rescue process, including the crucial factors which affect the provision of services required at random in real life. The model takes into account physical locations

of stations and resources; capabilities and characteristics of resources; policies affecting selection of resources to be assigned to cases, manning levels for shifts and vehicles, and acceptable levels of service provided; and weather and sea conditions. In addition, the nature and rate of arrival of case loads are based on historical precedents, but can be varied at the discretion of the user.

Special care was taken during development of the model to insure that characteristics of simulated cases and services were realistic and internally consistent, and that the processes simulated reflected the same order and similar detail as those encountered in reality. Some simplifications were, perforce, required for the sake of economy and ease of operation, but artificialities have been kept to a minimum. The validity of the model has been tested and will be reported on in the near future. However, some discussion will be offered in the latter part of this volume as a prerequisite to establishing credibility and confidence in use the simulation.

In simplest terms, the search and rescue model exemplifies a typical queueing problem wherein customers (i.e., cases requiring Coast Guard services) enter the system at random times to be serviced by one or more facilities (that is, here, Coast Guard resources). A customer being serviced ties up one or more serving facilities for an amount of time dependent on the location of the case and the type and amount of service required. Accordingly, new customers may arrive in the system and have to wait (in a queue) until an appropriate facility



is released on completing its last service or, perhaps, priorities may require breaking off service in progress, putting the less serious case into a queue. On the one hand, the desire to satisfy "customers" might occasion the acquisition of enough service facilities to keep queueing and waiting time to a minimum. However, it might be considered unacceptable if expensive facilities were maintained in a standby, but idle, condition to achieve the aforementioned objective. Central to this problem, moreover, is the stochastic nature\* of the arrivals and servicing, hence the need to balance requirements for long-term, steady-state satisfaction of needs with the possibility of temporary overloading of the system during peak periods or unusual circumstances.

It might be noted here that the foregoing remarks apply to queueing problems in general, and are not elements peculiar to the SARSIM. In fact, one of the uses of the simulation model is to explore reactions of given allocations and deployments of forces to marked increase in demand, etc.

#### AN OVERVIEW OF SARSIM

The Search and Rescue Simulation Model (SARSIM) is an event-oriented computer program based on the theoretical search and rescue model discussed just above. The simulation is keyed to specific events, such as the arrival of cases requiring service, completion of service by one or more assigned resources, interruption of service by an assigned resource which must be reassigned to a case of greater

\*A stochastic process is a highly variable sequence of events characterized by randomness of occurrence at each point in time.



severity, etc. Consequently, operation of the program proceeds from one significant event to the next, with an internal (simulated) clock keeping track of the simulated passage of time. (To illustrate the nature of this process a sample simulation of a simple SAR situation is presented in Appendix A.)

The computer program must be written exactly to account for all possible eventualities within the simulation. There must be an appropriate ordering of all necessary decisions and explicit rules for all conceivable alternatives. The simulation then effectively compresses time to a high degree, completely ignoring the passage of time during which nothing significant transpires.

SARSIM is comprised of three major program packages, one or more of which may be employed to explore a particular set of conditions. The first major component in the sequence is the PREPROCESSOR, or PREPRO, founded on a historical accounting of cases served by Coast Guard stations. As described in general terms in the following section (and in greater detail in Volumes II and III of this series), PREPRO is used to generate the timing of case arrivals and the specification of requirements for service. In other words, PREPRO supplies a scenario, or a preliminary "event list" which may, if desired, be used for many different computer runs.

The heart of SARSIM, the OPERATIONAL SIMULATOR (or OPSIM), is essentially a bookkeeping system which logs in arrivals, registers their needs, investigates the availability of service facilities, assigns

resources for servicing, and generally keeps track of simulated time spent in the several possible activities represented within the model. OPSIM is described in somewhat more detail below and is fully documented in Volumes II and IV of this series.

The third major component is the POSTPROCESSOR (or POSTPRO). This program module permits the calculation of a variety of statistics of interest to the user, either as a supplement to the output from OPSIM (which is tailored for use by the analyst) or to enhance the usability and comprehensibility of the program's output. POSTPRO is also described in a little more detail below and in fine detail in Volumes II and V of this series.

A comparative recapitulation of the SAR and SARSIM processes may be useful as a guide for following the descriptions which follow in the next three sections:

(a) Actual cases occur at random times; each case has a specifiable location and a particular set of needs for service. SARSIM reproduces typical cases and randomizes their injection into the simulation within the PREPROCESSOR.

(b) When the Coast Guard receives notice of a case requiring service, a suitable resource is dispatched, if available. SARSIM similarly reviews available resources for suitability in assignment. Both the real and the simulated systems keep track of cases waiting for service if facilities are not available. The OPSIM portion of the model makes resource assignments, as well as maintaining statistics

of interest.

(c) The Coast Guard periodically assesses SAR performance, including collation of data on individual stations, districts, resource types, and classes of cases. Similar statistics are provided as the output of OPSIM. In addition, POSTPRO permits specialized sorting and analysis of data of particular interest.

#### THE PREPROCESSOR(PREPRO)

The Preprocessor, or PREPRO, serves two major purposes in preparing for runs of the simulation model. The first of these is data extraction from magnetic tape records based on actual cases served by individual Coast Guard Stations. PREPRO derives pertinent parameters from these records and develops a historical case file for an entire district. The file includes information on the types of emergencies, severity of cases, characteristics of personnel or property involved, weather and sea conditions, number and kinds of services rendered for search and/or assistance, etc. The historical file also includes a chronological listing of the past occurrence of actual cases for the entire district (i.e., the cases from all individual stations combined).

At the option of the user of the simulation, PREPRO may be used to generate a scenario based on the historical file of actual cases, but with the order of occurrence determined by random selection. The user also has the option of selecting the case load, that is, the average rate of arrival of cases either by case type, or by station, or by district as a whole. This permits examination of growth in

demand, level demand, or possible decrease. The user also specifies the duration of the period to be simulated, either in "calendar" time or by number of cases to be examined.

The output of the PREPRO is a magnetic tape listing the historically or randomly ordered event list, plus a tabulation of the statistics of the scenario generated. It may be observed that a randomly ordered list of events may be re-used for as many runs as one chooses with variations in other inputs.

It should also be noted that the scenarios prepared at this stage are in accord with the statistics of the past and are internally consistent. However, if desired by the user of the simulation, attention can be paid to specific kinds of variation in demand for services, including general or specialized growth. For example, cases may be injected to reflect new types of service demands and specialized peak loads.

### OPSIM

OPSIM, the central portion of the simulation model, accepts demand schedules for service from the PREPRO output and determines the number of needs to be served, assigns resources, and measures how well services are supplied. A set of input parameters, having been specified at the discretion of the user\*, OPSIM rapidly calculates how the SAR system would react to the given combination of demand and resources.

\* See list which follows immediately

For example, a summer's case load for an entire district can be simulated in about 10-15 minutes running time on the computer.

The critical inputs which can be varied by the user to capitalize on the wide-ranging flexibility of the model include the following:

(a) Capabilities and characteristics of each type of resource employed, including endurance, hourly operating cost, relative cost, speeds achievable in various operating modes, time to refuel, reliability and maintainability, and associated delay times.

(b) Locations of stations in district and listing of adjacent interactive stations, aircraft-covering stations, and cutters; numbers of resources of each type assigned to each station; and crew manning levels during each shift at each station.

(c) Data on number of weekday and weekend shifts and times shifts end.

(d) Tolerance times for each severity level, that is, maximum acceptable time until resource arrives to provide service or for searching, depending on the seriousness of the case.

(e) Selectable data relating to searching procedures, especially with regard to daylight searching.

(f) Policy selections, especially with regard to use of resources, viz., when station receiving call for service uses only its own resources, or whether resources from adjacent stations may be utilized.

Once the demand, resource, and policy inputs have been prescribed, OPSIM operates on the cases and keeps track of pertinent statistics.



In effect, as each case arrives into the system the needs associated with it are examined, including the possibility that search will have to be instituted or that two or more resources may have to respond. If appropriate resources are available to service a given need\*of the case, a particular resource facility is assigned on the basis of assignment policies and either (1) greatest operating economy achievable from among all those resources which can satisfy tolerance time; or (2) the resource which can arrive soonest if tolerance time cannot be met.

If no suitable resources are idle when the demand for service arises, ongoing service to a case of lower priority may be interrupted. If no suitable resources can be assigned, the case is placed into a queue for cases of the same severity with subsequent periodic review of status. When resources complete services, they become available for reassignment to other cases or to return to station.

At each change in status (e.g., cases entering or leaving queues, resources assigned to or completing services, etc.), corresponding changes are made to running counts of each type of event and the simulated time spent in each.

At the completion of the operational simulation a file may be prepared on tape of the various case attributes for subsequent analysis within the PostProcessor. In addition, OPSIM also generates a printout including the following types of data:

(a) District statistics

\*Each need is considered separately as the requirement for resource allocation becomes known.

(1) Number of cases which occurred; number of cases completed; the number of failures due to lack of suitable resources in system or at primary and adjacent stations; and the number of failures to satisfy prescribed tolerance times.

(2) Average utilization statistics overall, by shifts, and by resource types; of boats, cutters, C-130's, and other aircraft.

(3) Number of standby call-ups and unproductive standby call-ups.

(b) Station Statistics

(1) Counts of cases for which resources from given station were assigned to cases or were first to arrive on scene; failures of the types listed in (a)(1).

(2) Number of queues; number of interrupted services.

(3) Average times for resources to transit to cases and for cases awaiting service; average waiting times when tolerance exceeded and average of time in excess of tolerance.

(4) Miscellaneous station statistics, including calculation of a figure of merit, standby call-ups, unproductive call-ups, and utilization figures.

(c) Statistics on groups within district, similar to those for stations.

(d) Resource statistics, including number of times assigned and average utilization indices.

(e) Printout of attributes of exceptional cases, such as any needs which cannot be met with any available resources.



(f) Utilization statistics and average times, as under station statistics, segregated by weekday and weekend.

(g) Lists of cases remaining in queue and all busy resources at the end of the simulation.

#### THE POSTPROCESSOR (POSTPRO)

The foregoing list of the OPSIM outputs illustrates how the data presented, although fairly detailed, are to a considerable extent aggregated over what might easily be a large number of quite varied cases. The function of POSTPRO is to enable the user to acquire statistics of interest for a more highly selected group of cases. To this end, the details of individual cases may be accumulated on tape by OPSIM for manipulation within POSTPRO.

POSTPRO has what is termed "QUICK QUERY," a computer routine which enables the user to specify classes of cases of special interest (such as cases occurring in a particular geographic area or at a given minimum distance from shore and also requiring tow, etc.), as well as formulas for desired calculations and the sequence in which the output is to be produced.

#### CREDIBILITY OF THE SIMULATION MODEL

As stated earlier, considerable effort was devoted to establishing realism in the analytical model by invoking the aid of operationally - experienced Coast Guardsmen and attempting, to the maximum extent possible, to pattern the model after actual Search and Rescue practices. This

meant careful attention to the choice of significant events and to the sequence and manner of effecting assignments within the system.

In addition, certain internal parameters had to be assigned numerical values: these were set and varied in a series of calibration runs for each district investigated. Using the historical data files, cases can be (and were) presented to the simulation exactly as they occurred in time and space. Comparison of the statistics produced by OPSIM after simulated SAR were made with similar statistics for the actual events. There was good agreement between the two sets of data, to be documented in a forthcoming report on the analysis of validation tests.

Another set of tests, which are also to be reported on in the cited upcoming report, demonstrated that outputs changed in the expected direction when slight changes were made to selected input parameters.

#### GENERAL EXAMPLES OF THE USE OF SARSIM

As should now be clear, SARSIM is a tool with which a manager may explore the likely effects of conceivable changes to the SAR system. It not only supplies data on expected performance for one particular set of inputs, but may also be used to ascertain the effect of selective variations, including changes made on the basis of results derived in a preceding set of runs. The use of the simulation model provides a widely-expanded base of information which the decision-maker may consider, along with subjective judgments, prior to choosing a course of action.

It is also noteworthy that the executive need not know the inner workings of the program in any great detail, nor need he know the language of the computer. An analyst, serving as intermediary, converts the user's desires and the pertinent background information into the machine parameters necessary to activate the simulation. The analyst should also be responsible for translating and presenting the output data from OPSIM and POSTPRO. The executive may then exercise his option of accepting or rejecting -- or of revising his initial questions and occasioning some additional computer runs.

The kinds of simulation runs which might arise are illustrated in two following examples.

(1) If two stations within a given district are to be closed (as was actually scheduled to occur), what effect would this be expected to have on the provision of SAR services?

It might be anticipated that the loads previously handled by these stations would be taken up by their immediately adjacent neighbors in roughly equal shares. However, it might not be obvious in advance whether, with the two stations closed, service to clients would suffer. The simulation showed that over 80% of the cases previously handled by the two closed stations were indeed picked up by the nearby shore stations, but in unexpectedly unequal fractions: the disparity seems to be due to the geographical locations of the particular stations involved and the sites of case occurrence relative to these stations of interest. (The other cases not reassigned to nearby shore stations

were handled by cutters or aircraft.)

With the two stations closed, there were no increases in the number of failures to meet prescribed tolerance times (i.e., maximum allowable waiting times) at the shore stations which took up the slack, but there was an additional failure of this type occurring at one of the covering aircraft stations. It is also interesting to note that waiting times for clients served by the adjacent shore stations were essentially unchanged (in fact, they went down by about 1 minute). At the same time, the average waiting times for clients served by the stations picking up the extra load went up about 10 minutes. In other words, the simulation revealed that the two stations to be closed were serving distant cases, causing extensive waits. Closing these stations would then be expected to increase utilization at nearby stations, but without causing undue waits for the clients.

(2) If a new resource, such as an air cushion vehicle (ACV) becomes available, to what extent and benefit would it supplement or replace existing resources?

This problem might be explored by selecting a district and specifying various mixes of old and new resources. The simulation might be run to represent a future summer with considerable growth in case loads. Given the performance capabilities of the ACV, a scenario would be generated in PREPRO, then run through OPSIM for each of the sets of input values, corresponding to the prescribed resource mixes.

The results of such a simulation could be compared with one

another to indicate the relative costs of those mixes which afforded the same levels of SAR services or, if costs were fixed, the mixes offering minimum waiting times for the most severe (or for all) cases, etc.

Reviewing the preceding examples, it should be clear that the simulation model, in essence, interprets the effects of choosing a particular set of input conditions which describe the resources available and the service demands to be exerted on the system. Granting that the model is, indeed, an adequate representation of the real world search and rescue system, SARSIM's predictive ability is strictly limited to man's ability to forecast the input elements, including uninvented resources and future waterborne crises. In this regard, however, the simulation can be of great assistance by permitting examination of unusual peak demands for service.

As suggested by the first of the examples cited, the simulation may well produce somewhat unexpected results. Such surprises must be carefully examined for clues as to cause, for they frequently provide insights into situations whose intricacies are not readily apparent.

#### CONCLUDING REMARKS

The intent of this volume has been to offer the executive a broad overview of the nature of the Search and Rescue Simulation Model (SARSIM). The level of detail presented has been restricted to that necessary for a general understanding of the processes involved, as well as the benefits and limitations associated with its use. The relationship of the model



to SAR problems has been illustrated in the text, and a micro-scale simulation is exemplified in Appendix A. The reader who is interested in exploring SARSIM in finer detail is referred to Volume II of this series, which provides Analyst Level Documentation. (The remaining volumes are dedicated to Programmer Level Documentation, and are intended for use by those directly concerned with machine runs.)

Finally, the accompanying table is a guide to the approximate costs for making different kinds of computer runs with SARSIM. Ranges of values are shown in some instances since there are uncertainties with regard to the degree of complexity likely to be encountered. In particular, it should be observed that PREPRO runs which simulate a month's load or less can provide a menu of ten scenarios; only a single scenario is produced for the costs shown for longer periods. However, as stated earlier, a single scenario may be re-used over and over within a district for many sets of resource inputs. The costs shown for POSTPRO are subject to considerable variation, depending on the complexity of queries. It should be recalled that POSTPRO is used selectively when particularized manipulation of OPSIM output data is desired.

APPROXIMATE COSTS FOR SARSIM RUNS\*(in dollars)

Time Simulated	No. of Cases	PREPRO COSTS	OPSIM COSTS	POSTPRO COSTS
1 Day	30	20#	10	15-30
1 Month	1000	30#	20-40	40-100
3 Months	3000	35##	40-80	150-350
1 Year	10000	75##	125-250	300-850 or more

\* For one district

# 10 scenarios provided

## 1 scenario provided





## APPENDIX A

### A SAMPLE SIMULATION OF A SIMPLE SAR SITUATION

The example which follows has been designed to illustrate how a SAR situation might be simulated. Although the methodology followed is completely analogous, the SARSIM model is, of course, far more complex in terms of numbers of stations, resources, decision rules, and so forth. Nonetheless, the material in this appendix may be useful for supplying an appreciation of the concept operation, and use of a simulation model.

The types of cases requiring SAR services will be classified here as being either serious or non-serious. It is assumed on the basis of past records that the distribution of severity of cases will continue to be in the ratio of 5 -to- 1, non-serious over serious. It is furthermore anticipated that half of the cases will continue to involve equipment failures, one-third will require evacuation from positions of peril, and the remaining one-sixth will necessitate search.

The resources to be examined in this situation, specified by the user of the simulation, are a helicopter and a utility boat, to be assigned to cases in accordance with the policy rules established in Table A-1. The figures in parentheses indicate the probabilities of occurrence stipulated above. It may be noted, as shown in the table, that all probabilities have been selected as multiples of sixths,

hence, if desired, the simulation may be played manually\* by rolling dice, specifying in advance the association between each possible die position and the event to be associated with it.

Table A-1

Resource Assignments for Simple SAR Simulation

(Figures in parentheses indicate probability of occurrence of indicated event)

Red Die Face	Nature of Distress	Severity of Case	
		Non-Serious (5/6)	Serious (1/6)
1,2,3 (1/2)	Equipment Failure (1/2)	Boat	Both
4,5 (1/3)	Evacuation (1/3)	Boat	Helo
6 (1/6)	Search (1/6)	Helo	Both
	Green Die Face	1,2,3,4,5 (5/6)	6 (1/6)

The SAR situation which is being simulated consists of a series of cases which randomly arrive into the system; which are placed in queues (waiting lines) if service facilities are not immediately available or which are serviced if the necessary facilities are available; which require variable amounts of

\*This was done experimentally to produce the results furnished below.

service, hence time for servicing; and which leave the system when services have been completed. The essential nature of the simulation is that it is keyed to events (such as arrivals, servicing, and departures); an internal (simulated) clock keeps track of time, completely ignoring the passage of time during which nothing significant transpires. Effectively, time is drastically compressed, provided that decision rules have been established within the program to account for all possible events, with an appropriate ordering of simulated actions.

For this simulation, it remains to assign mechanisms for determining arrival and service times. For illustrative purposes only, it is assumed that lapses of (precisely) 40, 80 or 120 minutes between successive arrivals to the system are equally likely. A roll of a red die might then be used to determine the onset of each new case, with faces 1 or 2 indicating a lapse of 40 minutes since the last case arrived; faces 3 and 4 for an 80-minute lapse; and faces 5 and 6 for a 120-minute lapse. Similarly, the following mechanism was chosen to determine service time for cases:

Green Die Face	Probability	Service Time (min)
1	1/6	30
2, 3, 4	1/2	60
5	1/6	90
6	1/6	180

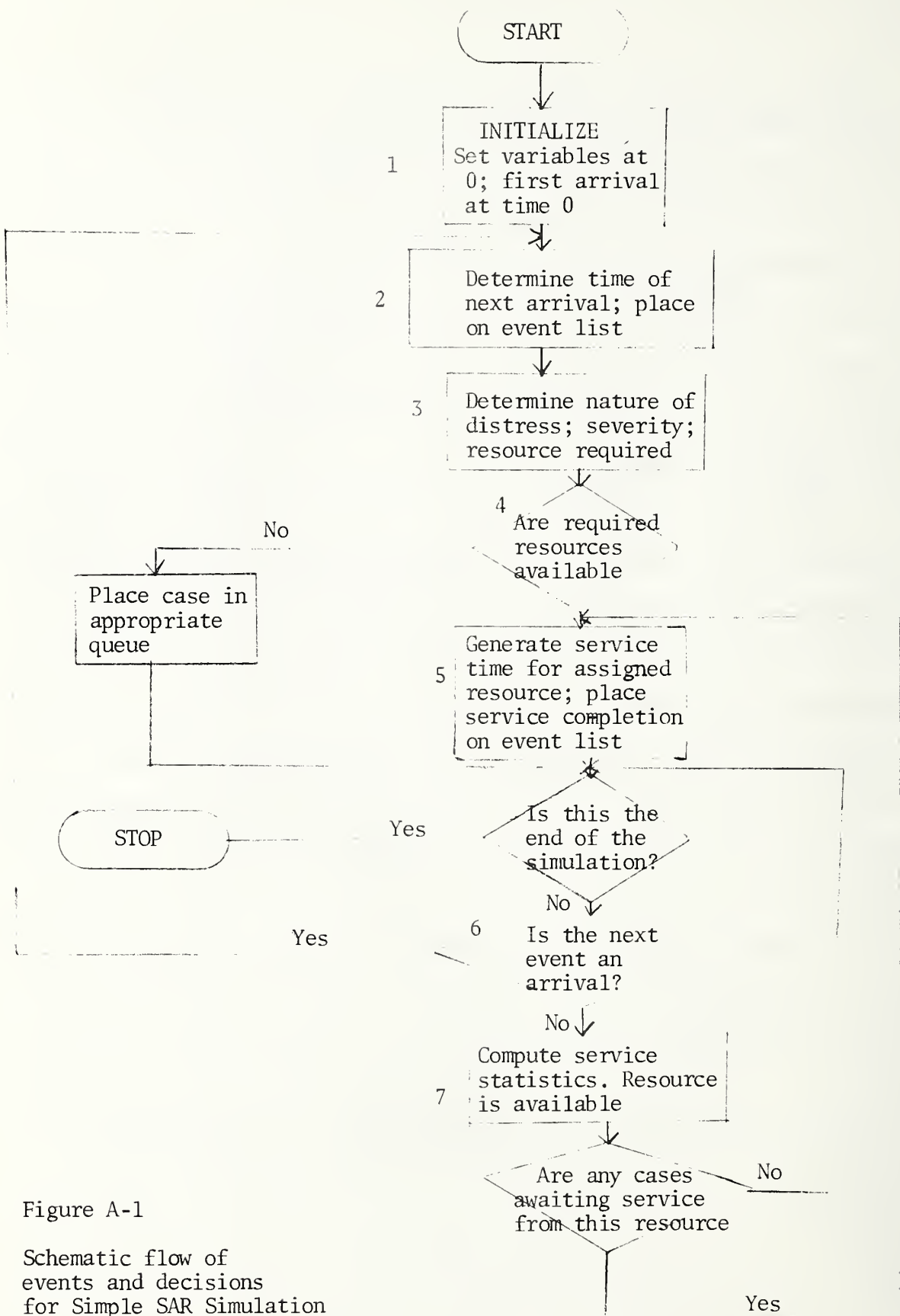


Figure A-1

Schematic flow of  
events and decisions  
for Simple SAR Simulation

Even for this simple SAR system, the number of events and alternatives is fairly large and must be carefully and exactly accounted for, as illustrated schematically in the flow chart of figure A-1. The sequence may be described, with commentary, as follows:

1. Initialize the system and go to Step 2. All variables including clock time and numbers of cases in queue or in processing, are set at zero; first case will arrive at time zero.

2. Determine the time for the next arrival to the system; place the item on an event list; go to Step 3.

In this example, the red die would be rolled to determine whether the next case would follow its predecessor by 40, 80, or 120 minutes.

3. Determine the nature of the distress and the case severity to determine the required resource(s); go to Step 4.

Both dice would be rolled to determine whether the boat, helicopter, or both would be required, as shown in Table A-1.

4. Assign available resources to case; go to Step 5. If resources are busy, place case in appropriate queue; go to Step 6.

Separate queues are maintained for serious and non-serious cases awaiting service while resources are tied up. As resources become available, queues are examined, as indicated in Step 7.

5. Generate a service time for assigned resources; compute time of completion of service; place event on the event list in its proper chronological order; go to Step 6.



The green die is rolled to select service time, as described above. Case arrivals and service completions are both placed on the event list in their chronological order of occurrence. The random arrivals may therefore occur while facilities are tied up or after they have been freed.

6. Determine the type of event next on the event list: if it is an arrival, advance the simulated clock and go to Step 2; if it is a completion, advance the clock and go to Step 7.

7. Compute the busy time for the resource which has just completed service; search the queue for serious cases to determine whether this resource can be utilized; if so, calculate the waiting time in queue for the case to be serviced now, remove that case from the queue, and go to Step 5. If there are no serious cases awaiting the newly-freed resource, examine the non-serious queue to determine if the resource can be used; if so, proceed as with serious case. If the resource is not needed by any cases in queue, go to Step 6.

The process is continued, as outlined above, until some specific number of cases have been run or some other indicator of the end of simulation occurs. In retrospect, it will be seen that a random set of arrivals has been generated, each occasioning an assignment of the boat or helicopter or both for a random choice of servicing time. During the course of the simulation, queues may have been established for either or both of serious and non-serious cases awaiting assignment of a busy resource. The bookkeeping features of the process have accounted

for numbers of cases in queues, time spent waiting, times spent in servicing cases, and total elapsed time within the simulation. It becomes possible, then, to prepare summary statistics of the type shown in Table A-2, derived from a manual simulation of 100 cases in accordance with the simulation rules described in this appendix. The table also shows results of a second simulation, run in the same general fashion, but using two boats and one helicopter as available resources. The additional boat was intended as a means to reduce the average waiting time for the non-serious cases; the differences between the two sets of figures derive largely from the availability of the second boat, but are also strongly affected by the vagaries of chance. Thus, for example, the apparent increase in average waiting time for serious cases is solely attributable to the fact that, in the second running of the simulation, the single serious case which had to wait for a resource arrived while another serious case was being processed.

It must be emphasized that the sample simulation shown in this appendix is a pure invention for illustrative purposes only. It is highly artificial, not merely with regard to its simplistic nature, but also by virtue of the fact that the sets of resources, arrival and service rates, and assignment rules bear small resemblance to actuality. Despite its simplicity, it should be obvious that this simulation process is complicated and time consuming; the more complex SARSIM clearly requires computerization.

Table A-2

## Summary Results of Two Sample Simulation Runs

	First Sample	Second Sample
Number of boats available	1	2
Number of helicopters available	1	1
Number of cases in run	100	100
Number of serious cases	17	17
Number of serious cases to queue	4	1
Probability of serious case queueing	$4/17=.24$	$1/17=.06$
Average waiting time, serious cases	15 min	20 min**
Number non-serious cases to queue	45	13
Probability of non-serious case q'ing	$45/83=.54$	$13/83=.16$
Average waiting time, non-serious cases	111 min	85
Helicopter time available*	8070 min	8070 min
Helicopter time busy	3330 min	3270
Boat time available*	8070 min	16140 min
Boat time busy	5940 min	6210 min

\* In this context based on duration of simulated run. This takes no account of manning considerations, etc.

\*\* Based on single case in queue; see text.



