Wheight

NATIONAL BUREAU OF STANDARDS REPORT

10 431

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

VOLUME II

ANALYST LEVEL DOCUMENTATION

Technical Report to
United States Coast Guard
Plans Staff, Office of Operations

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, 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 a Center for Radiation Research, an Office of Measurement Services and the following divisions:

> Applied Mathematics—Electricity—Heat—Mechanics—Optical Physics—Linac Radiation[2]—Nuclear Radiation[2]—Applied Radiation[2]—Quantum Electronics[3]—Electromagnetics[3]—Time and Frequency[3]—Laboratory Astrophysics[3]—Cryogenics[3].

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; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials and the following divisions:

> Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Reactor Radiation—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 leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute also monitors NBS engineering standards activities and provides liaison between NBS and national and international engineering standards bodies. The Institute consists of the following technical divisions and offices:

> Engineering Standards Services—Weights and Measures—Flammable Fabrics—Invention and Innovation—Vehicle Systems Research—Product Evaluation Technology—Building Research—Electronic Technology—Technical Analysis—Measurement Engineering.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch 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; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:

> Office of Standard Reference Data—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

[2] Part of the Center for Radiation Research.

[3] Located at Boulder, Colorado 80302.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
4314561

June 1971

NBS REPORT
10 431

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

VOLUME II

ANALYST LEVEL DOCUMENTATION

By
S. S. Karp, M. D. Maltese

Technical Report to
United States Coast Guard
Plans Staff, Office of Operations

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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
Linda K. Cummings
Mary Jane Duberg
William Elliott, III
Walter G. Leight
Joel Levy
Elizabeth E. Leyendecker
Marcia D. Maltese
Patsy L.B. Saunders*
Wayne A. Steele
Michael R. Vogt
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
Thomas T. Matteson
Gerald L. Underwood
Robert R. Wells

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

Mary M. Abbott
Theresa I. Conrad
Frances E. Jones
Lucinda I. Farrell

* Staff members of the NBS Applied Mathematics Divison

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

FOREWORD

The United States Coast Guard has recently been responding to more than 40,000 distress incidents per year in the coastal and inland waters of the continental United States which are under their jurisdiction. They have aided recreational boaters, commercial fishermen, and other individuals in maritime distress, preventing or limiting loss of life and destruction of property.

Projections of future recreational boating shows an average increase of 4.4% per year*. This increase alone might soon impose severe demands on Coast Guard services to be rendered to the general public. For this and similar reasons, the Coast Guard must make strategic plans for the Search and Rescue (SAR) missions, with regard to procurement, allocation, and organization of resources within budgetary constraints for any selected time frame.

The tools of management science, systems analysis and operations research readily lend themselves to the type of problem represented here. Accordingly, the National Bureau of Standards, in a joint effort with the Coast Guard**, has developed a Search and Rescue Simulation Model (SARSIM) to assist Coast Guard management in its approach to planning for future SAR activities.

*"Long Range Forecase of Activities in the Marine Environment with Implications for Planning Coast Guard Search and Rescue Operations", National Planning Association, Washington, D.C., Feb. 22, 1971, Executive Summary p. 10

**Karp, S.S. and T.T. Matteson, "The Integrated Team Concept, of Simulation Model Development", Proceedings of the 1971 Summer Computer Simulation Conference.

SARSIM is a highly flexible, user-oriented model. It simulates Coast Guard response to an input caseload scenario, i.e., people and/or property in distress. The automatic summary output from the model (e.g., response times, resource utilization statistics, etc.) gives the user considerable insight for judging the effectiveness of the SAR system with regard to each input scenario.

The user is offered a variety of modes in which to operate the model. For example, he can prepare, automatically, a multitude of client demand scenarios. He can perturb the SAR resource inventory, i.e., vary the number and classes of resources, their physical capabilities, their deployment (location), and manning levels. He may also choose to exercise the model with different server disciplines (resource assignment schemata). In addition, the user can supply criteria to be applied to the simulated case history output for additional optional analysis.

In summary, SARSIM offers flexible, built-in capabilities to aid Coast Guard decision makers in developing long range strategic plans to carry out the SAR mission.

Part I - Introduction and Background

1. Problem Definition

Need

Because of the rapid and continuing growth of marine activity, especially in recreational boating, combined with the constraints imposed by national budget allocations, the Coast Guard has found it necessary to examine its current readiness postures and operating policies and to project future Search and Rescue (SAR) Force Level Requirements on an integrated resource basis. That is, the Coast Guard's aircraft, cutters and shore stations with their associated boats must be considered simultaneously as a system in order to plan properly for the entire SAR mission.

In order to provide insight to evaluate the system comprehensively on a unified basis, a methodology had to be developed and associated criteria, or measures of effectiveness had to be created to help analyze the various SAR mission alternatives.

Typically, management is concerned with determining the best mix of resources to accomplish the SAR mission, simultaneously answering such queries as:

- How many resources of each type should be procured (or phased-out)?
- Where should the resources be deployed to achieve maximum effectiveness?
- What are the most cost-effective crew manning readiness levels for each Coast Guard station, for various times of year, week, day?

- What are the differences among various operating tactics?
- What are the effects on the system of the introduction of new resource types, having increased capabilities?
- What are the effects of introducing different organizational structures, such as grouping the facilities of store stations?

Objective

The initial objective of this study was to assess the feasibility of various methodologies to assist Coast Guard management in answering the questions posed above; and given its feasibility, to propose the design for the most promising methodology. Underlying this goal was the study team's desire to provide management with a highly realistic, flexible tool to examine the SAR system under a wide range of conditions. Since direct experimentation with the system is probably infeasible because of its potential danger to human life, it quickly became apparent that a model of the SAR system would most likely be necessary.

Description of the SAR Process

The Coast Guard's search and rescue activities constitute a fairly complex process, characterized by heterogeneous classes of clients in distress. Furthermore, depending on the type of distress and the urgency with which assistance is required, there may be available a wide variety of types of SAR resources to serve the clientele. Resources differ in capability, related to their physical attributes and the environmental conditions at the time of an incident.

SAR incidents may involve peril to people or the threat of damage to or loss or property. Occurrences of distress incidents tend to cluster at "preferred" locations or peak time periods, but are generally widely enough distributed around the average times and places that they seem to occur, to all intents and purposes, at random. The needs for assistance also vary widely, and include rescue of personnel in the water, search for lost vessels, extinguishing of fires, dewatering of flooded vessels, help with repairs or replacement of damaged material, or towing to safety.

The Coast Guard resources dedicated to SAR are, for the most part, located at shore stations along coasts where distress incidents are most often experienced. These stations are grouped into about a dozen major districts* and several minor districts (which are either geographically small or which serve relatively few cases). The major districts contain from 30 to 50 stations, called Operating Facilities (or OPFAC's), at which are stationed about 80 - 150 rescue-capable units (resources) categorizable into some 15 - 20 resource types. Short stations with small boats handle the bulk of the SAR incidents encountered. They are supported by fixed-wing aircraft and helicopters at nearby Coast Guard air stations, as well as long-range aircraft which might be stationed at considerable remove outside the district. Covering Coast Guard cutters are also available to assist, either from shore stations or while operating independently on SAR patrol at sea.

The SAR process may be viewed as a spatially distributed queueing system in view of the areal extent of SAR cases and the decentralized

---

*Coast Guard districts generally consist of several contiguous states and are numbered like U. S. Naval districts.

deployment of Coast Guard resources. Coast Guard receipt of notification of a distress situation corresponds to the random arrival of a client ("customer" in the text book sense). The resources at the station receiving the notification may or may not be capable of responding to the call for assistance, depending on the combination of pertinent factors. These include the location of the incident relative to the station, the characteristics of the unit in distress, the nature and seriousness of the distress, the environmental conditions, and the physical and operational characteristics of the local resources. Thus, for example, a small boat might not be capable of operating effectively in high seas, or might not be able to tow a larger boat.

Capable resources assigned to a station might not permit response to a call for assistance if, for example, they were all busy on other cases, or "down" for maintenance, or not fully manned. Consequently, availability at the time of call must be considered along with capability.

Dependent on established policies, resources from nearby shore stations (or covering air stations and cutters) may be called upon to render the necessary SAR services. Whatever policy has been set, a capable resource is assigned if such is available. If assignment cannot be made, the client will perforce wait (in a queue, as it were) until the earliest feasible assignment. However, if the seriousness of the situation warrants, ongoing service to an earlier arrival might well be interrupted to attend to a higher priority case. At each station several queues may exist simultaneously, each containing cases of the same priority in the order of their arrival into the system. The highest priority queue will be served as capable resources become available, and in the order in which cases arrived. Only after that queue has been emptied will lower priority cases be handled. (Provisions may also be made to review the priority of waiting cases and raise it, if necessary or desired.)

It is clear from the foregoing abbreviated discussion that there are compound interactions among the clients (i.e., the cases of distress) who enter the system, the inventory of local resources at the notified station and their status, neighboring and covering stations and the status of their resources, priority interrupt and resource assignment policies, the ambient conditions at sea, and other applicable factors. These interrelationships contribute to the difficulty in selecting an approach for modeling of the SAR process, and hence had to be examined in considerable detail to assure a reasonably accurate analytical facsimile.

Scope

The study leading to the simulation model reported herein was limited in scope to include only the SAR mission of the Coast Guard. Its other missions such as law enforcement, aids to navigation, merchant marine safety, etc., are preemptible by a SAR incident and can be reasonably excluded.

Only surface vessels and air resources have been considered in the study. More specifically, cases which cannot be aided by the above categorized resources. (such as "overdues" located through communications checks, cases requiring medical advice, or cases aided by a station's motor vehicle) are not considered.

The study was to be open ended relative to time frame. That is, the end product methodology had to be futuristic in concept such that, for example, the projected demand over a ten year period could be applied and the force requirement determined; or new equipment and operating techniques could be considered without redesigning the methodology.

However, in the interest of providing meaningful data to the Coast Guard management, some macro-level of organization is preserved. By using the Coast Guard district as the system boundary in examining the problem, pertinent variables could be considered in more detail than, for example, if the entire East Coast operation were modeled as a whole. The selection of the district level of organization as a boundary is further justified by the relative independence of operations from district to district. To be realistic, however, particular interdistrict activities are also considered simultaneously when examining the system on an intradistrict basis. This approach was an obvious requirement since certain long-ranged aircraft resources are made available to handle cases along a single coast. In bounding the problem in such a fashion, no loss of important interaction among the districts is encountered.

Of course, a subset of the model should be exercisable so that if the user chose to apply the methodology to an organizational level of lesser magnitude than the district (e.g., a single station), he might do so, provided that he recognizes that the results are localized to that level. In short, simulation at any organizational level is permitted, but the limitations imposed by the required level of detail for meaningfully modeling the search and rescue system, the level of station interaction and queueing, and the available computer storage, all contribute to the definition of these bounds. Further, these last two constraints also place an upper bound on the number of cases that can be examined simultaneously, thus bounding somewhat the time frame, (e.g., a month, a peak period) of a single model exercise.

The study approach does not encompass the causative factors involved in SAR cases. Boating safety education, although important to the entire SAR problem, is not considered in the study, as the incidences are taken as given. The objective here, then, is to examine alternative ways of serving a given forecast caseload so that the Coast Guard can compare the performance and cost of each alternative as part of its long range planning and evaluation effort.

2. Alternative Methodologies

The recommendation to examine the feasibility of developing a model of the SAR system, with emphasis on measuring resource utilization on an integrated basis, was made to Coast Guard management (as reported in the Second Interim Report on a Multi-year Special Analytical Issue Study, June 1969) by the Plans Staff, in the Office of Operations, USCG. This group had already developed a simple queueing model for a single Coast Guard shore (small boat) station, applying the Poisson arrivals/Exponential service time queueing formulations to determine the number of servers (boats, crews) required to provide a given level of service for that station's caseload. These shore stations have a relatively homogeneous set of servers (small boats) and a high incidence of arrival of the typical case, making the closed form model a reasonable predictive tool for resource analysis for a single shore unit.

The Technical Analysis Division at the National Bureau of Standards was called upon to examine the entire integrated SAR problem, offer its recommendations as to the proper methodology, and subsequently to complete the study as a joint endeavor with the Coast Guard. Three basic methodologies became apparent to the study team. The first approach is to perform certain well planned experiments directly with the SAR system, collect empirical data, and measure the effects of the experiment. Second, the analytical model approach may be applicable, if the client/server relationships can be extended to represent the integrated SAR system in closed form. A third approach, the development of a large scale simulation model, could be undertaken so that indirect experiments might be undertaken with a realistic model of the SAR system.

To apply the direct experimentation approach in the real world is extremely risky for the Coast Guard from two viewpoints. First, the chances of getting useful results are not very promising because of the difficulties of conducting closely controlled experiments on the operational system. Coast Guard experience indicates that field personnel do not always comply with the experimental rules. For example, when a case is to be queued, often an additional resource would be dispatched to service it "illegally" to avoid any possible risk. More importantly, however, the risk associated with the possible loss of life or destruction of properties, when the system is undergoing experimentation, is one that could carry serious moral, legal and political implications, each of which is desirable to avoid.

A review of the literature* has indicated that the state of the art in the development of analytical models of sophisticated, highly complex queueing systems has not advanced sufficiently to be applied to the SAR system, without the drawback of making over-simplifying assumptions. For example, the heterogeneity of the physical capabilities of the several different resource types make the analytical modeling approach essentially untractable for investigating the trade-offs of various resource type mixes for servicing a given caseload. Some additional complications are: Calls for service are distributed over time and geography according to distributions that

---

* See references 1 through 11

are known only empirically; the service process is of priority interrupt type, and a client's priority may change as a result of either undergoing service or of being interrupted, or both; the needs of the client may vary widely in both type and amount -- for example, a case may be a simple single resource tow lasting a half hour or a complex search case involving several aircraft, cutters and boats for a week or more. Although queueing systems with some of the above characteristics have been examined in the literature, the combination of all of these complexities, and many more, does not appear to solvable analytically. And if a sufficiently complex analytical model could be developed, it would undoubtedly consume a considerable amount of time and money, to the point that its solution would probably not be timely.

Simulation, the third approach, although also costly in both design time and money, has the potential of yielding the most flexible methodology, and could perhaps provide the best payoff to Coast Guard management.

Simulation modeling is preferred over controlled real-world SAR experimentation since it avoids the risks of direct experimentation with the general public. Furthermore, simulation offers considerably more flexibility than the limited experiments which might be undertaken directly. Simulation modeling is also preferred to analytic modeling where the problem characteristics prohibit timely solution with current state of the art. The SAR response devolves on a fairly complex set of decisions within a hierarchy of a formal organization. These decisions encompass the differing physical capabilities of the inventory of SAR resources, the environmental conditions at the time of the incident, the service requirements of each client, the server disciplines, etc. Often such complex problems can be formulated analytically, but cannot be solved analytically in a timely fashion for immediate use. Although the analytic approach could work if the complexities of the SAR system could be sufficiently simplified, such an approach would almost certainly fall short of adequately answering Coast Guard management's questions.

Frequently, simulation is considered only as a "last resort" after other problem approaches are considered lacking and not applicable. Certain unique properties of the simulation approach, however, do make it attractive to the analyst in preference to other techniques.

To illustrate, it may desirable to observe the dynamic behavior of a process, especially a man-system-environment problem such as SAR, and collect a variety of simulated data. Since the ratio of simulated time while observing this behavior to the actual time can be very small, a large assortment of experiments can be performed. Often simple performance criteria for evaluating a system just do not exist; or the observers of the system may evaluate its performance quite differently. These last two points make simulation more attractive as the approach to solving the SAR problem, as a single static point solution leaves Coast Guard management without a spectrum of resultant observations both, aggregate and detailed, for making the best decision for SAR planning.

A secondary value of simulating a system is its use in developing and testing tactical operating policies and procedures. Often, portions of the simulation model, close replicas of the real system, can be used as training devices (similar to operational games), allowing the user to change input conditions, make decisions during the game and observe the system response. Not only can this become an effective training device, but it also can provide insight when the user is interested in certain dynamic interactions, rather than the overall behavior of the system.

There are drawbacks to simulation in that the development and exercise of such a complex model could prove to be very expensive. However, when it is realized that a savings of only 1% of the $150 million annual budget for SAR could easily repay the investment several times over, the expense of simulation does not seem so critical.

The question always arises as to the validity of a simulation model (or any model or empirical examination of a problem). Model validation is indeed a topic in itself, and is treated in a separate report, but some thoughts are noted briefly in this section.

Validation, too, can be expensive, and even unproductive, but there are reasons to believe, before building the simulation, that a successful validation for the SAR model is possible. First, there exists a relatively good and complete data base of SAR incidents. Second, the SAR model can be constructed so that it is essentially deterministic in nature (as opposed to probabilistic). Thus, the confidence that it is a good replica of the SAR system can be gained from a few simulation exercises and a comparison of the simulation results with some carefully prepared statistics generated from historical data. In contrast, if the simulation were highly probabilistic, many exercises would be necessary to gain assurance that the model is an adequate replica of the system.

In summary, the simulation approach has been selected as the methodology for studying the SAR problem because of its several advantages, few disadvantages and high probability of success.

3. Design of the Simulation

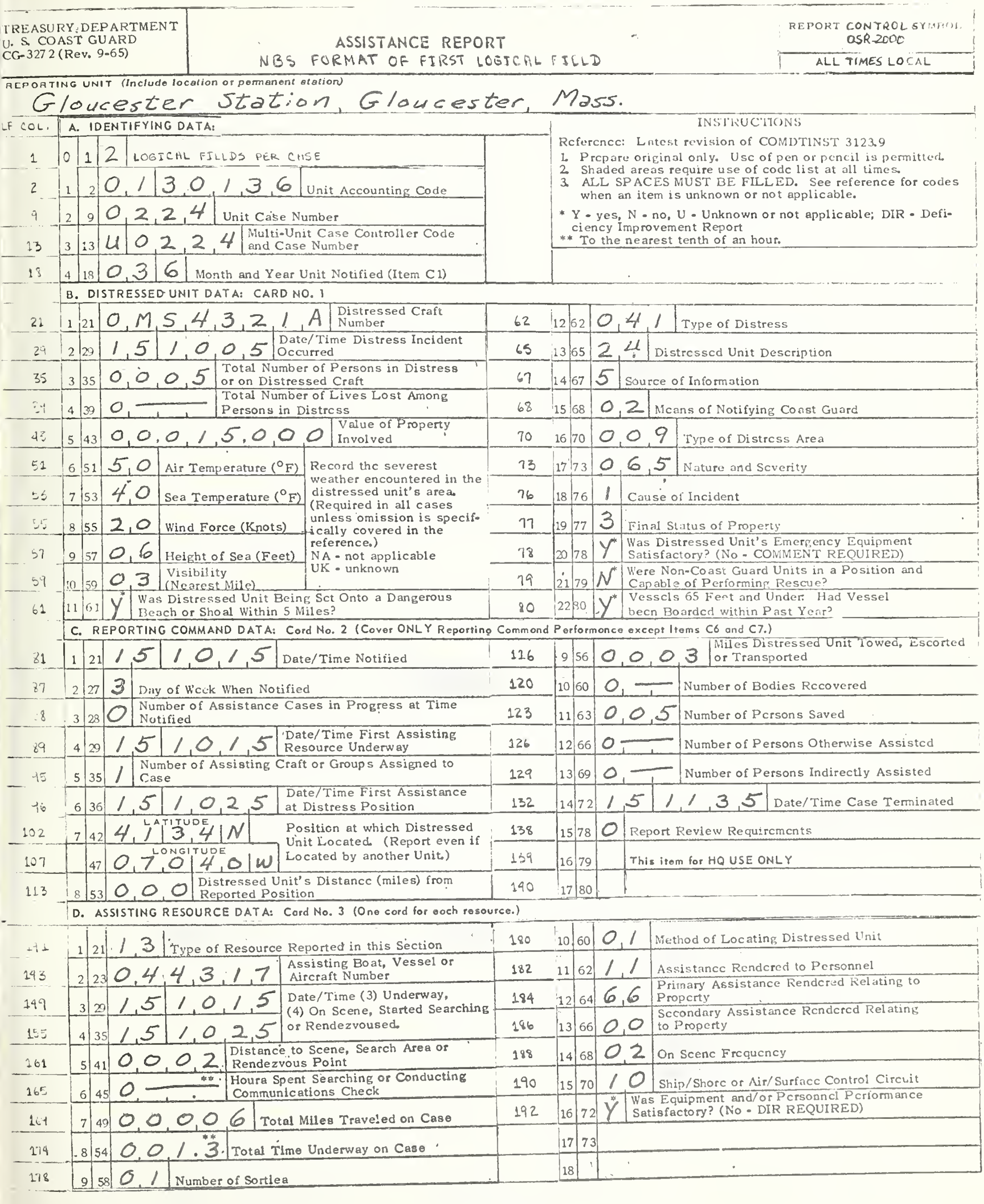
The purpose of this section is to review the major design considerations which were analyzed during the design phase of the Search And Rescue SIMulation (SARSIM) model. It is felt that this section will be helpful towards obtaining a fuller understanding of the descriptions of the algorithms of SARSIM presented in Part II of this volume.

Inputs and Outputs

A simple yet effective way of viewing the overall SARSIM model is via its inputs and outputs. The inputs to the model are in part dictated and constrained by the available SAR data base. The core of the data base is the set of SAR Assistance Reports which are filled out for each distress case the Coast Guard answers. Figure 1 shows a sample report and indicates the kind of information that is available. In retrospect, almost every item on this form is used in SARSIM either directly, via parameters calculated from these items; for post-processing analysis (e.g. "Value of Property Involved"); or for validation comparisons. Further, much of this data was used during the design process to verify many of the model's assumptions.

Three years of this data (approximately 40,000 cases per year) were cleaned, organized, sorted, and merged at the National Bureau of Standards just prior to and during the early stages of the simulation development. Although many automatic checks were made during the cleaning of this data, some key punch errors and inconsistencies may still exist, not to mention the possibility that the information may

SAMPLE ASSISTANCE REPORT



TREASURY DEPARTMENT
U. S. COAST GUARD
CG-3272 (Rev. 9-65)

ASSISTANCE REPORT
NBS FORMAT OF FIRST LOGICAL FIELD

REPORT CONTROL SYMBOL
OSR-2000

ALL TIMES LOCAL

REPORTING UNIT *(Include location or permanent station)*
Gloucester Station, Gloucester, Mass.

INSTRUCTIONS

Reference: Latest revision of COMDTINST 3123.9
1. Prepare original only. Use of pen or pencil is permitted.
2. Shaded areas require use of code list at all times.
3. ALL SPACES MUST BE FILLED. See reference for codes when an item is unknown or not applicable.

* Y - yes, N - no, U - Unknown or not applicable; DIR - Deficiency Improvement Report
** To the nearest tenth of an hour.

LF COL.	A. IDENTIFYING DATA:			
1	0	1	2	LOGICAL FIELDS PER CASE
2	1	2	0130136	Unit Accounting Code
9	2	9	0224	Unit Case Number
13	3	13	U0224	Multi-Unit Case Controller Code and Case Number
18	4	18	036	Month and Year Unit Notified (Item C1)

B. DISTRESSED UNIT DATA: CARD NO. 1

21	1	21	0MS4321A	Distressed Craft Number
29	2	29	151005	Date/Time Distress Incident Occurred
35	3	35	0005	Total Number of Persons in Distress or on Distressed Craft
39	4	39	0 —	Total Number of Lives Lost Among Persons in Distress
43	5	43	000015000	Value of Property Involved
51	6	51	50	Air Temperature (°F)
53	7	53	40	Sea Temperature (°F)
55	8	55	20	Wind Force (Knots)
57	9	57	06	Height of Sea (Feet)
59	10	59	03	Visibility (Nearest Mile)
61	11	61	Y*	Was Distressed Unit Being Set Onto a Dangerous Beach or Shoal Within 5 Miles?

Record the severest weather encountered in the distressed unit's area. (Required in all cases unless omission is specifically covered in the reference.)
NA - not applicable
UK - unknown

62	12	62	041	Type of Distress
65	13	65	24	Distressed Unit Description
67	14	67	5	Source of Information
68	15	68	02	Means of Notifying Coast Guard
70	16	70	009	Type of Distress Area
73	17	73	065	Nature and Severity
76	18	76	1	Cause of Incident
77	19	77	3	Final Status of Property
78	20	78	Y*	Was Distressed Unit's Emergency Equipment Satisfactory? (No - COMMENT REQUIRED)
79	21	79	N*	Were Non-Coast Guard Units in a Position and Capable of Performing Rescue?
80	22	80	Y*	Vessels 65 Feet and Under: Had Vessel been Boarded within Past Year?

C. REPORTING COMMAND DATA: Card No. 2 (Cover ONLY Reporting Command Performance except Items C6 and C7.)

81	1	21	151015	Date/Time Notified
87	2	27	3	Day of Week When Notified
88	3	28	0	Number of Assistance Cases in Progress at Time Notified
89	4	29	151015	Date/Time First Assisting Resource Underway
95	5	35	1	Number of Assisting Craft or Groups Assigned to Case
96	6	36	151025	Date/Time First Assistance at Distress Position
102	7	42	LATITUDE 4134N	Position at which Distressed Unit Located. (Report even if Located by another Unit.)
107		47	LONGITUDE 07040W	
113	8	53	000	Distressed Unit's Distance (miles) from Reported Position

116	9	56	0003	Miles Distressed Unit Towed, Escorted or Transported
120	10	60	0 —	Number of Bodies Recovered
123	11	63	005	Number of Persons Saved
126	12	66	0 —	Number of Persons Otherwise Assisted
129	13	69	0 —	Number of Persons Indirectly Assisted
132	14	72	151135	Date/Time Case Terminated
138	15	78	0	Report Review Requirements
139	16	79		This item for HQ USE ONLY
140	17	80		

D. ASSISTING RESOURCE DATA: Card No. 3 (One card for each resource.)

141	1	21	13	Type of Resource Reported in this Section
143	2	23	044317	Assisting Boat, Vessel or Aircraft Number
149	3	29	151015	Date/Time (3) Underway, (4) On Scene, Started Searching or Rendezvoused.
155	4	35	151025	
161	5	41	00002	Distance to Scene, Search Area or Rendezvous Point
165	6	45	0 — **	Hours Spent Searching or Conducting Communications Check
169	7	49	000006	Total Miles Traveled on Case
174	8	54	001.3 **	Total Time Underway on Case
178	9	58	01	Number of Sorties

180	10	60	01	Method of Locating Distressed Unit
182	11	62	11	Assistance Rendered to Personnel
184	12	64	66	Primary Assistance Rendered Relating to Property
186	13	66	00	Secondary Assistance Rendered Relating to Property
188	14	68	02	On Scene Frequency
190	15	70	10	Ship/Shore or Air/Surface Control Circuit
192	16	72	Y*	Was Equipment and/or Personnel Performance Satisfactory? (No - DIR REQUIRED)
	17	73		
	18			

FIGURE 1

SAMPLE ASSISTANCE REPORT (continued)

NBS FORMAT FOR SUCCESSIVE LOGICAL FIELDS

1	0		NUMBER OF D-CARDS PER CASE				
3	1	21	Type of Resource Reported in this Section	42	10	60	Method of Locating Distressed Unit
5	2	23	Assisting Bost, Vessel or Aircraft Number	44	11	62	Assistance Rendered to Personnel
11	3	29	Date/Time (3) Underway, (4) On Scene, Started Searching or Rendezvoused	46	12	64	Primary Assistance Rendered Relating to Property
17	4	35		48	13	66	Secondary Assistance Rendered Relating to Property
23	5	41	Distance to Scene, Search Area or Rendezvous Point	50	14	68	On Scene Frequency
27	6	45	** Hours Spent Searching or Conducting Communications Check	52	15	70	Ship/Shore or Air/Surface Control Circuit
31	7	49	Total Miles Traveled on Case	54	16	72	* Was Equipment and/or Personnel Performance Sstisfsctory? (No - DIR REQUIRED)
36	8	54	** Total Time Underway on Case	55	17	73	
40	9	58	Number of Sorties	56	18		
	D. ASSISTING RESOURCE DATA: Card No. 3 (One card for each resource.)			D. ASSISTING RESOURCE DATA: Card No. 3 (One card for each resource.)			
57	1	21	Type of Resource Reported in this Section	96	10	60	Method of Locating Distressed Unit
59	2	23	Assisting Bost, Vessel or Aircraft Number	98	11	62	Assistance Rendered to Personnel
65	3	29	Date/Time (3) Underway, (4) On Scene, Started Searching or Rendezvoused	100	12	64	Primary Assistance Rendered Relating to Property
71	4	35		102	13	66	Secondary Assistance Rendered Relating to Property
77	5	41	Distance to Scene, Search Area or Rendezvous Point	104	14	68	On Scene Frequency
81	6	45	** Hours Spent Searching or Conducting Communicationa Check	106	15	70	Ship/Shore or Air/Surface Control Circuit
85	7	49	Total Milea Traveled on Case	108	16	72	* Wss Equipment and/or Personnel Performsnce Satisfactory? (No - DIR REQUIRED)
90	8	54	** Total Time Underway on Case	109	17	73	
94	9	58	Number of Sorties	110	18		
	D. ASSISTING RESOURCE DATA: Card No. 3 (One card for each resource.)						
111	1	21	Type of Resource Reported in this Section	150	10	60	Method of Locating Distressed Unit
113	2	23	Assisting Boat, Vessel or Aircraft Number	152	11	62	Assistance Rendered to Personnel
119	3	29	Date/Time (3) Underway, (4) On Scene, Started Searching or Rendezvoused	154	12	64	Primary Assistance Rendered Relating to Property
125	4	35		156	13	66	Secondary Assistance Rendered Relating to Property
131	5	41	Distance to Scene, Search Area or Rendezvous Point	158	14	68	On Scene Frequency
135	6	45	** Hours Spent Sesrching or Conducting Communicstions Check	160	15	70	Ship/Shore or Air/Surface Control Circuit
139	7	49	Total Milea Traveled on Case	162	16	72	* Wss Equipment snd/or Personnel Performance Satisfactory? (No - DIR REQUIRED)
144	8	54	** Total Time Underway on Case	163	17	73	
148	9	58	Number of Sorties	164	18		

HAVE YOU PREPARED ONE SECTION D FOR EACH CRAFT OR GROUP INDICATED IN ITEM C5?

NAME OF DISTRESSED CRAFT	NAME AND ADDRESS OF OPERATOR	NAME AND ADDRESS OF OWNER IF DIFFERENT
Mary Kay	A. B. See 1020 Main Street Gloucester, Mass.	—

COMMENTS *(List names and addresses of persons reported in C10 and C11)*

Andrew B. See - Same as above
Joseph C. See - " " "
Andrew B. See, Jr. - " " "
Lee J. See - " " "
John J. Jones - 1022 Main St., Gloucester, Mass.

DATE SUBMITTED	SIGNATURE	REVIEWED AND FORWARDED	DATE	INITIALS
3/16/66	ABE L. SEAMAN		3/16/66	GGC

have been erroneously recorded at the origin Despite these facts, this data base represents a valuable resource for the design, operation and validation of the model.

The exogenous inputs, then, for SARSIM are the historical cases and their attributes, for example: date and time of notification, location, environmental conditions, assistance rendered (need), case severity, search requirements, etc.

The endogenous inputs are used to describe the SAR system to be simulated. These user inputs include: district identification; station data (including, for each station: location, number and types of resources, covering aircraft stations and cutters, crew manning levels for each shift, etc.); resource type data (including for each resource type: operating costs, endurance, speeds capabilities reliability, etc.); shift data; tolerance times as a function of severity levels and case type; standby data; and many more descriptors of the system to be simulated.

The outputs for a given run, or exercise, of the model can be categorized into two basic types. First are case outputs,which include such summary statistics on the cases serviced during the simulation exercise as: average waiting time; average service time; number of incidents of interrupts and queueing; etc. The second type are the system outputs,which measure such things as the utilization of resources (overall, by station, by resource type, by time period etc.); number of system failures; number of standby call-ups, etc.

The outputs described above are all automatically printed after every run of the model. Additional information can also be obtained concerning case outputs via a postprocessor program. If the user chooses to have this additional output, he can specify that an output case tape be created; then the postprocessor can use this tape to retrieve, analyze and print out the additional statistics desired by the user.

Boundaries

The choice of the district as the basic boundary of the model has already been discussed. (See, in Section 1, the discussion under "Scope.")

Methodology for Treating Time Advance

An investigation of the SAR data base revealed that, even during the peak boating season, on the average only about 3 to 5% of the SAR resources are busy at any particular time. In other words, there is very little "interesting" (i.e., SAR) activity during most of the time. On the other hand, when cases do come up, the amount of activity is very high and the average time between significant events becomes small. For these reasons it was decided that the time advance mechanism in the model should be discrete, rather than continuous, and event oriented rather than time interval oriented. This approach is highly efficient for SARSIM, since the computer need do no work during the long periods of inactivity; yet during periods of high activity, the computer will be able to simulate all of the interesting events regardless of how fast they occur. SARSIM then has been modeled as a discrete event digital simulation.

Level of Detail

Any simulation is limited in the number of events it can handle efficiently. The district caseload (approximately 7000 per year) is sufficiently small that multiple events for each case can be considered. Therefore, for each case, in addition to origination and termination, it will be possible to simulate other events such as notification, response/launch, on scene, interrupt(s), priority change(s), and searching, etc. in order to make the model more realistic. These added events will, for example, allow a resource enroute to a case to be diverted to another case of higher priority (i.e., interrupt). It will also allow a case in progress to have its priority change (in either direction) to reflect changing conditions and assistance already received.

Since the Coast Guard desired to investigate alternative resource mixes, it was not sufficient that the simulation merely assign the same resource type to a given case as was assigned historically. Therefore, a highly sophisticated set of resource assignment algorithms had to be designed such that the preferred resource (or resources, for a multi-resource case) is selected from all the existing resources being simulated for assignment to each case. The provision for priority interrupt, of course, further complicates these algorithms.

The resource assignment algorithm for long* search cases is

---

*Cases involving searches of less than one-half hour duration are handled separately.

somewhat more complex than for non-search cases because of the widely differing capabilities for search among the various resource types. However, the servicing of a search case in the model is less detailed than the servicing of a non-search case. This is due to the limited data available in the data base on how the search was carried out (e.g., search pattern, track width, etc. are not given) and also due to the relatively minor incidence of long search cases in the overall SAR system. Only a small fraction of the total SAR caseload involves a long search requirement. However, when such a case does come up, it consumes a considerable amount of (usually expensive) resource time. Therefore, the objective of servicing long search cases in the simulation was mainly to account for this resource utilization when the relatively unlikely event of a long search comes up -- because the resources occupied on a search case will not be available (unless interrupted) for the more common non-search cases. Hence the level of detail need not be as fine for these long search cases.

Selection of Programming Language

As a result of a comprehensive analysis of the available programming languages and associated computer systems, the SIMSCRIPT I.5 language was chosen for basic operational module of SARSIM. A report entitled: "Selection of Programming Language," Feb. 20, 1970, was delivered to the Coast Guard which presented this analysis and recommended this language.

FORTRAN V is used for the preprocessing programs because of its universality and suitability to these kinds of calculations. QUICK QUERY is used for postprocessing because it is compatible with the SIMSCRIPT language.

Methodology for Case Generation

The generation of the demand tape containing the exogenous case inputs is based on the SAR data base and, in particular, each generated case is obtained from the description of an actual case which has occurred historically. A discussion report of the advantages and drawbacks of this data base approach, as compared to a highly conditional Monte Carlo approach where each attribute of each case is obtained from conditional distributions, has been submitted* to the Coast Guard. These advantages are summarized here:

a. Using actual historical cases and their attributes precludes the possible generation of cases whose attributes are not entirely consistent within the case.

b. The conceptualization and development of a highly conditional Monte Carlo preprocessor that is both consistent and accurate would be highly time consuming. Much data analysis would be required to determine a feasible trade-off among the accuracy in generating cases, a manageable program, and the computer storage limitations.

c. Using historical cases and their attributes contributes to the task of validation. It is much more meaningful to

---

*Karp, S.S., "Alternatives for Geographically Locating SAR Cases," 5/11/70

Structure of SARSIM

For any programming system of the size and complexity of SARSIM, there exists a strong motivation to construct it in a highly modular fashion. The reasons for this are due to: (1) the economics of operating the model modularly; (2) the greater efficiency and simplicity of programming small, discrete modules; and (3) the advantage that the different functional parts can be written in different languages, each appropriate for its module.

A very natural organization for SARSIM was to divide the overall model into three major functional blocks: the Preprocessor (PREPRO), the Operational Simulator (OPSIM), and the Postprocessor (POSTPRO). The Preprocessor is a set of FORTRAN programs which prepares the exogenous demand tape from the historical SAR data files. This demand tape contains a chronological ordering of cases with their respective attributes. The user can vary the caseload either overall or by selected criteria, such as specific case parameters, to produce any desired forecast demand scenario. The Operational Simulator is the basic module of SARSIM. It is a discrete event digital simulation written in SIMSCRIPT which models the assignment of the preferred resource(s) and simulates the service of each case. It calculates certain summary statistics for standard output and can produce an output case tape for further detailed analysis by the Postprocessor. The QUICK QUERY* information retrieval system is used to provide this analysis.

---

*Developed for the Economic Development Administration by Consolidated Analysis Centers Incorporated, Santa Monica, California, U.S.A.

The economics of this approach are readily apparent. The costly and time-consuming task of preparing an exogenous demand tape can be done off-line in the Preprocessor. Once a satisfactory tape has been generated, it can be used numerous times by the Operational Simulator to compare the performance of alternative system configurations (e.g., different resource levels, mixes, locations, etc.) when using the same caseload scenario. The most promising of these runs can then be investigated in more detail via runs of the Postprocessor. This approach then can eliminate much unnecessary repetitive processing.

A further advantage in the case of SARSIM is that nearly all of the stochastic elements of the simulation can be resident in PREPRO, leaving OPSIM relatively deterministic. In this way, several runs of PREPRO can be made creating several different scenario tapes, because each is started using a different random number seed. (The program currently allows for ten different scenarios to be generated during a single execution of PREPRO.) Summary statistics are also output on each scenario allowing the user to select an appropriate demand tape from those created. The selected tape can then be input to OPSIM, which services these cases nearly deterministically. (The only randomness in OPSIM is in the probability of an on-line failure of the selected resource, and the probabilistic reevaluation of the case's severity during its service.) This not only makes OPSIM very efficient in its processing of the caseload, but also fewer repetitions of OPSIM runs are now required because of the small variance in OPSIM outputs due to these minor stochastic effects. Similarly, as mentioned previously, a relatively deterministic OPSIM is far easier to validate than a stochastic representation.

Each of the three functional blocks of SARSIM is further functionally modularized. The PREPRO organization is very straightforward; its five basic parts are: (1) a set of "cleaning routines" to edit and correct errors in the data base; (2) a set of data processing programs to sort and organize the data base such that it is compatible with the requirements of OPSIM; (3) a program for calculating additional case parameters required by the OPSIM program; (4) a program for randomly generating caseloads; and (5) a program for generating caseloads in their historic, chronological order (for validation purposes).

The organization of OPSIM is based primarily on a partitioning of the types of SAR cases encountered in actual practice. Although this partitioning can be done in several ways, a very natural and manageable categorization became apparent in terms of the multiplicity of resources responding to a case. An examination of the SAR data base revealed that about 85% of all cases are serviced by a single Coast Guard resource, while the remainder required two or more resources. Further, the simulation of the selection process for assigning the preferred resource(s) to a case is conceptually very different from the simulation of the servicing of a case. For these reasons, it was advantageous to construct the Single Resource Assignment Subroutine (SRAS) as the basic module of OPSIM.

Cases requiring a multiplicity of resources are handled by the Multi Resource Assignment Subroutine (MRAS). MRAS relies heavily on part of SRAS in assigning the individual participants to a multi-resource case. In addition, MRAS performs the scheduling of the several resources on a given case, provides for continuous coverage of the distress client, and simulates the coordination necessary for such events as multiple (hand-off) tows and interrupt of a resource involved in a multi-resource case.

Simulation of the service of both single and multi-resource cases is performed by the Service Subroutine (SS). In addition to scheduling all the service functions that must be performed, SS also calculates the statistics that are output at the conclusion of the OPSIM run.

Because both the assignment rules and the servicing of long search cases are very different than for non-search cases (as was discussed previously), a separate module for simulating long search cases was constructed. The Search Assignment and Service Subroutine (SASS), as the name implies, simulates both the assignment of resources to search cases as well as the service of this portion of a case. If at the conclusion of a search the client requires additional service, either SRAS or MRAS, as appropriate, is called by the OPSIM Executive Routine (OPSIM EXEC) to complete the case.

OPSIM EXEC performs similar control functions on other types of cases as well as managing such interface functions as maintaining queue discipline and interrupt control. It also handles such "bookkeeping" functions as terminating the simulation of cases at the appropriate time and calling the statistics and output programs within OPSIM.

The Postprocessor is composed of two functional parts. The File Definition and Maintenance (FDM) software is used to actively create (define) the file of output cases from OPSIM, or to modify an existing file, so that it is compatible with the requirements of the QUICK QUERY language. The Quick Query Program (QQP) is used used to passively access this file for data retrieval, manipulation and display. Generally FDM is run only once for a given output from OPSIM, while QQP may be run several times to obtain different analyses and statistical printouts. This is another, although minor, example of how the economies of operating the model modularly are achieved via the SARSIM structure.

Model Assumptions

As a result of much analysis of the SAR data base, and discussions with many Coast Guard officers having operational SAR experience, together with the necessity of making simplifications because of constraints on computer storage, execution time, etc., several simplifying assumptions were made. The most major of these were presented earlier under the Section "Scope." The more important of the remainder are given below.

1. Primary Station Assignment

In the actual SAR system the assignment of a case to a shore station is generally made on the basis of the stations' geographical "area of responsibilities." Because of the difficulty of treating this in the model (due to complex, sometimes concave areas), and because these areas would have to be redefined everytime a station was added, deleted, or its location changed, a simpler approach was taken. This approach is that the station closes to the location of the case, from among the station which handled the case historically and its adjacent stations, is assigned as the primary station. Note that the historical primary station does not necessarily serve the case in the model; this is described more fully in Part II, Section 3A (SRAS).

2. Sequence of Events

The macroscopic sequence of events in SARSIM has been fixed in order to prevent unnecessary complications. Thus, if any long search requirement exists, it must be performed first. If the client is found and requires further on-scene assistance, this is done next. Finally, if a tow or escort is needed, this will be simulated to conclude the case. It has been determined that very few exceptions to this sequencing have occurred in actual practice.

3. A Priori Search Requirement

Consistent with the objectives of the search routine, discussed earlier under "Level of Detail," the search requirement, in terms of total search miles, is known for a case before the search begins. The number of search miles to be searched in SARSIM is set equal to the amount searched for this case historically. Again, search is a background activity simulated to account for expended resource time. No attempt is made to optimize search procedures.

4. On-Scene Needs

The type of service a case requires has been defined in SARSIM as the need(s) of the case. Examples of on-scene needs (i.e., other than search or tow) are firefighting, dewatering, provide equipment, refloating, evacuate personnel, etc. The needs of a historical case are determined indirectly from its SAR Assistance Report from the three "Assistance Rendered" items (Figure 1). Since one need per resource is required by the model (See "Multi-Resource Cases" assumption, below) a dominance pattern had to be created so that the most important need per resource would be used. A description of how this is done is given in Part II, Section 2 (PREPRO).

5. Equi-Capability

Given the need of a case, its location and the environmental conditions, a subset of the district's resources are checked in the model to determine whether each is capable of serving the case. In so doing, the assumption of equi-capability is made with respect to the resource selection process. For example, if two different resources are both capable of serving the need of the case, under the given environmental conditions, regardless of the fact that the performance by one may be superior to the other, each is considered as fully capable, for purposes of resource selection. (Other factors, such as time of response, cost, busy-idle status, home station, etc. are also considered in the selection process for the set of capable resources.) In other words, capability in SARSIM is a binary decision.

6. Tolerance Concept

Basic to the resource selection algorithm is the concept that a distress client should be served within a given tolerance time which varies with (five levels of) his distress severity. All resources which are capable of serving the need of the client, under the existing environmental conditions, witin the tolerance time are considered equally satisfactory from a performance point of view. That is, a resource which could arrive earlier than the tolerance time is not given preference over one which would arrive later, but still within tolerance. (A ranking based on cost is made to select the preferred resource among those which can meet tolerance.) Only in the situation that no resources can meet the tolerance time, will preference be given to the faster resource.

7. Weather Conditions

Since actual historical cases are used in the generation of cases (see "Methodology for Generating Cases"), all weather descriptors for a given case are consistent. This avoids, for example, the possibility of having a case with 50 knot winds and calm sea state. However, using the option of random generation of cases, it is possible to have several simultaneous cases in the simulation system, but with different weather conditions. This was considered acceptable by the Coast Guard because it was felt that it was preferable to have internal consistency within a case, rather than consistency across cases. To provide both appeared to be a major effort, but one which would not produce significantly better results.

8. Multi-Resource Cases

Since SARSIM is basically a model which accounts for the utilization of resources, it is important that the simulation be able to replicate this utilization fairly closely. In the case of multi-resource responses to cases, it is difficult to determine from the cases' Assistance Reports why the given number of resources were used on a given case. That is, there exist many cases in the data base which appear to be very similar, yet a different number of resources were used on each case.

The basic assumption used for these multi-resource cases is that the simulation will respond to the same number of needs that were responded to historically. Although this approach has the disadvantage of limiting the investigation of alternative numbers of resources in serving these cases, it has the advantages of both simplicity of modeling as well as accuracy in replicating history. It should also be noted that only about 15% of all non-search SAR cases are multi-resource, therefore the effect of this assumption is not dominant.

9. Output Measures

Although most of the outputs are derived straightforwardly, some have inherent assumptions which need explanation for proper interpretation.

a. Exceptional Cases

These are cases which possess such unusual combinations of attributes that they cannot be served within OPSIM. This condition is usually due to an erroneous data item in the Assistance Report; it may also be due a resource which exceeded its rated capability historically to serve a case in distress. Also, certain air escort cases can become "exceptional cases" if unusual combinations of queueing and interrupt occur. This was accepted to avoid modeling a very complex situation which occurs for less than one percent of the caseload.*

b. Utilization Statistics

Utilization indices (in %) are calculated on the basis of the total number of resources of a given category, rather than on the number of "ready" resources. For example, a station having five boats of different types and two crews (i.e., two ready boats) which expended 72 hours of resource time on SAR cases during a month, will have a utilization of 2.0% (based on the five boats) rather than a utilization of 5.0% (based on the two crews). This method was used because it would not be possible

---

*However, a read-out is provided automatically to describe any such exceptional cases.

to obtain utilizations of resource types if crew utilization were used, since crews may serve on several different resource types. It is also important to note that this index is not used here as a measure of system performance, but rather as a check on the model's validity. Therefore, as long as the comparative historical utilizations are calculated in the same way, there should be no misunderstanding.

c. Waiting Time

The assumption inherent in the calculation of waiting time of a case is that is based on the first arrival of a resource to the scene of the incident. It is therefore this arrival time minus the case's notification time. Subsequent waiting, either due to delays of other resources (for a multi-resource case) or due to interrupt of the first resource after it has arrived on scene, is not included in the calculations. This is based on the notion that a client's anxiety will have been satisfied once the first resource arrives to assist him; also, the first resource is likely to overcome quickly the critical part of the incident in its first few minutes on scene. The remainder of the case is usually of a more routine nature. The output measures "C Failures" (cases waiting longer than their tolerance times) and "Demerit" (a measure of excess waiting time) are also based on this same concept of waiting.

REFERENCES

1. Benes, V. E. [1963] - General Stochastic Processes in the Theory of Queues (Addison-Wesley, Reading)

2. Cobham, A. - "Priority Assignment in Waiting Line Problems" Operations Research Vol. 2 (1956) pp. 70-76

3. Fortet, R. - "Définition Génerale des Processus de Service et Eléments pour leur Théorie" Revue Roumaine de Mathématiques Pure et Appliquées Vol. XII No. 9 (1967) pp 1235-1241

4. Jaiswal, N. K. - Priority Queues (Academic Press, 1968)

5. Karlin, S. and Mc Gregor, J. - "Many Server Queueing Processes with Poisson Input and Exponential Service Times" Pacific J. Math 8 (1959) pp 87-118

6. Kiefer, J and Wolfowitz, J - "On the Theory of Queues with Many Servers" Trans. Amer. Math. Soc. Vol. 78 (1955) pp 1-18

7. Keilson, J. and Kooharian, A. - "On Time Dependent Queueing Processes" Am. Math. Stat. 31 (1960) pp 104-112

8. Kesten, H. and Runnenberg, J. Th. - "Priority in Waiting Line Problems" Proc. Akad. Walt. Amst A. Vol. 60 (1957) pp 312-336

9. Schechter, M. - "On the Use of Computer Simulation for Research" Simulation and Games Vol. II No. 1 (1971) pp 73-88

10. Skinner, C. E. - "A Priority Queueing system with Server-Walker Time" Operations Research 15 (1967) pp 278-285

11. Takacs, Lajos - Introduction to the Theory of Queues (Oxford University Press, 1962)

Part II. Details of the Simulation

1. Introduction to Part II

The Search and Rescue Simulation Model (SARSIM) is an event-oriented computer program based on Coast Guard search and rescue activities, as discussed in Part I of this volume. It is comprised of three major program packages which may be employed flexibly to explore particular sets of input conditions. The remainder of this volume is devoted to comprehensive presentations for these major functional blocks of SARSIM: the PREPROCESSOR (PREPRO), the OPERATIONAL SIMULATOR (OPSIM), and the POSTPROCESSOR (POSTPRO). Particular emphasis will be placed on modeling the complex SAR system in OPSIM.

The simulation is designed to be exercised for a district, as defined by the Coast Guard. Selection of the district level was prompted by constraints imposed by limitations of computer storage, plus the fact that there is generally negligible interaction between districts except for the employment of long-range resources, such as the C-130. The limited number of these special resources, which are made available to any district on a given coast, are easily included in the resource profile and are exercised in the simulation for those cases requiring them.

The discussion of PREPRO explains the procedures and programs entailed in generating an exogenous Demand Tape; the programs are currently designed for use with the pre-Fiscal Year 1970 data format of the SAR Assistance Reports prepared by the Coast Guard for each case encountered.* The Demand Tape is then processed through OPSIM, where service for the case is simulated and summary statistics are collected and printed as standard output.

Finally, a prepackaged information retrieval system can be used in POSTPRO. A great deal of pertinent information is offered as standard output in the summary statistics provided by OPSIM, including utilization statistics for each type of resource and each stations, some "failure" data, and an exceptional case file (that is, cases which cannot be served). These data are highly aggregated, however, and may tend to mask out significant items of interest. The prepackaged concept for POSTPRO is an exceptionally attractive approach in that it provides a mechanism for filtering out special summary information on selected types of cases of particular interest to the user.

An overview of the structure of SARSIM is shown in the three related sections of Figure 2. Individual cases, with their description attributes, are prepared and ordered in PREPRO. Resources are assigned to provide services for these cases in OPSIM, which also generates output data with regard to cases and resources. More detailed analysis of the processed cases can be conducted in POSTPRO to satisfy requests for special information.

2. PREPRO - The Preprocessor for SARSIM

The fundamental purpose of PREPRO, the Preprocessor, is to prepare

---

*Treasury Department, U. S. Coast Guard, CG-3272 (revised 9-65) Assistance Report.

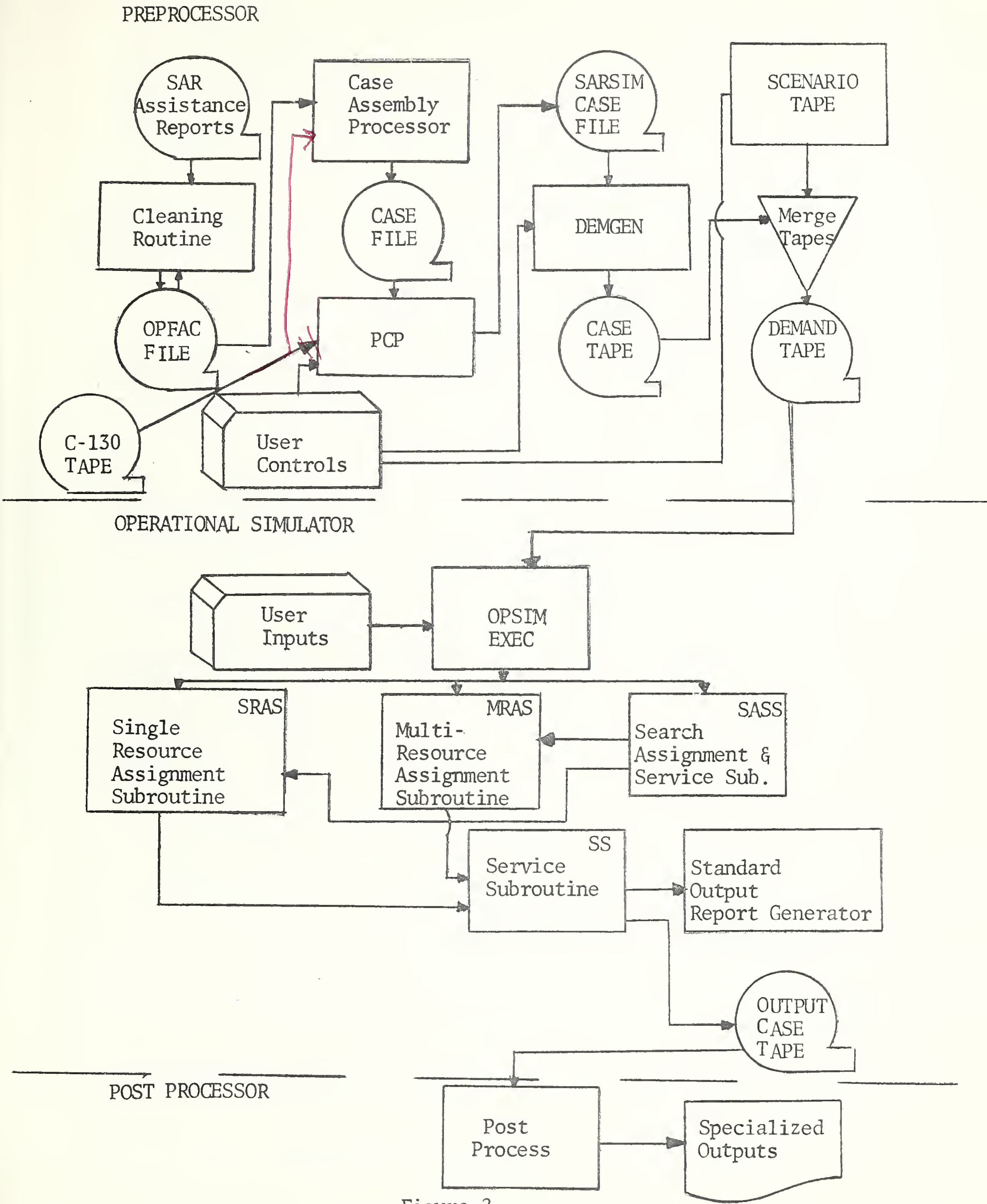


Figure 2
SARSIM Structure

an exogenous DEMAND TAPE, which is used to drive OPSIM. This DEMAND TAPE contains sufficient information about historically-derived case parameters to pass control to appropriate subroutines within OPSIM.

Conceptually, PREPRO may be separated into three major components: a report-editing routine, one for calculating case parameters for use in a scenario, and a third for generating an ordered caseload. (A fourth routine, the Case Assembly Processor, is also required to sort and collect similar cases requiring the services of two or more resources.)

Figure (3) shows the major subroutines and ordering of steps within PREPRO. These are described in detail in the following sections.

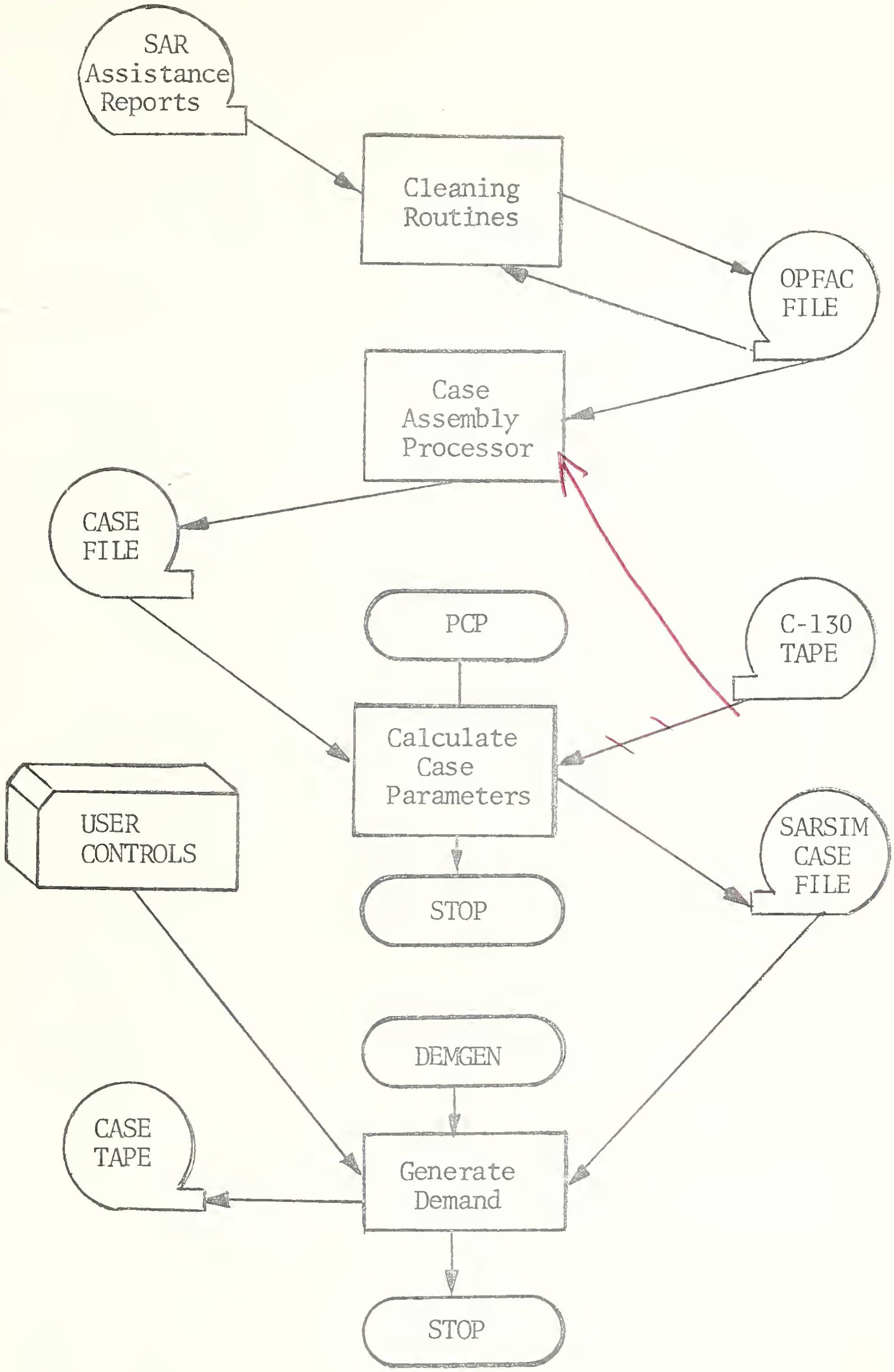
A. Cleaning Routines

A tape is prepared from historical SAR Assistance Reports, organized by the Operating Facilities (OPFAC's) within a given district. This tape is edited so that obvious errors are removed and there is internal consistency of the data. The Cleaning Routine results in an OPFAC FILE*. Those cases which required the services of two or more units are sorted and collected on their multi-unit case number to produce the CASE FILE, which then becomes the input to the Program for Calculating case Parameters (PCP) of PREPRO.

In addition to those cases occurring within the district and

---

*The term "FILE" is used in the sense of an unordered collection of case records. "TAPE" indicates a chronological ordering of case records.



Note: TAPE implies chronological order; FILE does not.

Figure 3
Major Steps in PREPRO

filed on the CASE FILE, special attention is given to those cases served by the long-range C-130 aircraft, both within and outside the district being exercised. These cases, filed on the C-130 TAPE, are input to the PCP for a determination of their case parameters via the Case Assembly Processor and Case File. The C-130 TAPE is prepared from the caseload at the air station from which the C-130's are deployed. For example, the cases at Elizabeth City, N.C. which were historically served by a C-130 are culled and written on the C-130 TAPE for the east coast of the Continental United States.

B. User Controls in PREPRO

The SAR Assistance Reports, as edited within the cleaning routine, are the basic input to PREPRO, but subject to controls supplied at the user's option. These options include specification of growth rates in demand for services at particular stations or for specified classes of clients, as well as the scenario description in terms of maximum number of cases to be generated or calendar data limits. For example, separate DEMAND TAPES can be generated for such scenario descriptors as peak season and non-peak season.

C. Program for Calculating Case Parameters (PCP)

Using information from the CASE FILE, the PCP calculates parameters required in OPSIM for each case, whether or not directly available in the historical case records. The data base may be for a single district for a single fiscal year or for three years, but all data must be consistent in format. (A developed program permits conversion of data from the "old" (pre-1970 format to the one currently in use, but not conversely.)

Some of the data for the simulation can be taken directly from the Assistance Report, while other data had to be devised using straightforward algorithms. Below is a list of case attributes developed in PCP which are the input to DEMGEN. Some of these parameters correspond directly to the pre-FY1970 SAR data format as described in USCG COMDT INST 3123.9A dated 31 March 1966. (Note that this Preprocessor is designed fgr the pre-FY70 data format and that modifications must be made for any other format.)

Case Attributes Developed in PCP

1. AIA: District in which the case occurred
2. STANO: Station number
3. A3: Case number
4. A4: Month and year the station was notified*
5. MINCI: Date and time the station was notified*
6. B3: Number of people on board
7. B5: Value of the vessel
8. B6: Air temperature
9. B8: Wind force
10. B9: Sea height
11. B10: Visibility
12. B12A: Type of distressed vessel
13. L: Length of Vessel
14. S: Severity i.e., relative seriousness/urgency of case
15. n: Number of needs other than search or tow
16. m: Number of resources that towed or escorted
17. NN: Total number of explicit needs:

    If $n = 0$ and $m > 0$, then $NN = 1$

    If $n > 0$ and $m > 0$, then $NN = n + 1$

    If $n = 0$ and $m = 0$, then $NN = 0$

---

*These values are combined into OCCUR, the date and time of notification.

18. γ: The degree of non-parallel service on a multi-resource case. The range is $0 \leq \gamma \leq 1$, where $\gamma = 1$ is the series service of the case. See Section 3B (MRAS) for further explanation.

19. t_e: Length of time spent on scene serving a multi-resource case. If $t_e = 0$, then the case is one of the following: (a) search; (b) tow; (c) escort; (d) search and tow; or (e) search and escort.

20. S_1: Equivalent number of resources operating in parallel on a long duration search case. If $S_1 = 0$, then the case does not involve a long search prior to serving any other needs.

21. S_2: Indicates if a short search is required before serving the first need.

$$S_2 = \begin{cases} 0, & \text{if there is no short search} \\ 1, & \text{if the resource serving the first need also searches for the client} \\ 2, & \text{if an additional resource is called to search for the client} \end{cases}$$

22. TSM: The Total number of Search Miles on a case. If TSM = 0, then both $S_1 = 0$ and $S_2 = o$.

23. MILES: The distance off shore

24. X

25. Y: Case location in nautical miles relative to a user input district origin. If the location is unknown, it is assigned a location. This is explained further in the text.

26. NEED(i): Explicit assistance requirement of the case.

27. tos(i): Amount of time spent on scene for serving need(i) tos(i) = 0 for search only and tow only cases.

28. $\Delta(i)$: Proportion of time into the multi-resource case completion that the subsequent resource commences service. $(0 \leq \Delta(i) \leq 1)$.

The inputs requred to operate PCP are the following:

1. CASE FILE: The SAR Assistance Reports have been processed through the Cleaning Routines and the inconsistences removed (with Coast Guard assistence). The Case Assembly Processor assembles multi-unit cases and prepares the CASE FILE. The CASE FILE thus contains all cases for a given district single unit and multi-unit, sorted on date and time of notification (earliest for multi-unit cases). Area cases which required resources from the district being exercised are also included and, in general, can be treated as multi-unit cases.
2. C-130 TAPE: The C-130 TAPE contains all cases that were served historically by a C-130 aircraft, from a single air station, sorted by date and time of notification.
3. District Location Data:
    - (a) District Origin: All case locations are referenced to an inputted district origin; (Origin Latitude and Origin Longitude.)
    - (b) BETA: Coefficient for calculating distances. (See next section).
    - (c) Unknown Case Location Data:

conversion of data from the "old" (pre-1970 format to the one currently in use, but not conversely.)

Some of the data for the simulation can be taken directly from the Assistance Report, while other data had to be devised using straightforward algorithms. Below is a list of case attributes developed in PCP which are the input to DEMGEN. Some of these parameters correspond directly to the pre-FY1970 SAR data format as described in USCG COMDT INST 3123.9A dated 31 March 1966. (Note that this Preprocessor is designed for the pre-FY70 data format and that modifications must be made for any other format.)

The inputs requred to operate PCP are the following:

1. CASE FILE: The SAR Assistance Reports have been processed through the Cleaning Routines and the inconsistences removed (with Coast Guard assistence). The Case Assembly Processor assembles multi-unit cases and prepares the CASE FILE. The CASE FILE thus contains all cases for a given district, single unit and multi-unit, sorted on date and time of notification (earliest for multi-unit cases). Area cases which required resources from the district being exercised are also included and, in general, can be treated as multi-unit cases. The CASE FILE also contains applicable data for C-130 cases in the district from the C-130 TAPE.
2. C-130 TAPE: The C-130 TAPE contains all cases that were served historically by a C-130 aircraft, from a single air station, sorted by date and time of notification. These cases enter PCP via the CASE FILE from the Case Assembly Processor.
3. District Location Data:
    (a) District Origin: All case locations are referenced to an inputted district origin; (Origin Latitude and Origin Longitude.)
    (b) BETA: Coefficient for calculating distances. (See next section).
    (c) Unknown Case Location Data:

i. For cases occurring in the district with no location given, a location is assigned the Cartesian coordinates $(x_i + \Delta x, y_i + \Delta y)$ from the historic primary station, i. Both Δx and Δy are user inputs and apply for the entire district. The coordinates (x_i, y_i) are also input for each station, i.

ii. For cases served historically by a C-130 aircraft but with no location given, a location is assigned corresponding to the district selected via Monte Carlo techniques. A distribution of C-130 cases across the districts is input along with a C-130 case centroid location for each district. (This centroid represents that location where most C-130 cases occurred in that district.)

(d) Search Speeds: For each resource type, L, the search speed, $SOA_3(L)$ is required to calculate TSM.

(e) Information for translating the assistance rendered historically, to property and personnel, into the needs of the case used within the simulation.

(Note that the special cull conditions for removing certain cases,(such as communications checks,) from the SARSIM Case File and the decision point for distinguishing between a long search and a short search are internal to the program, and not user input.)

The PCP processes a case at a time, generating the proper parameters relative to whether the case is single resource, multi-resourced, or a search case. Figures (4) through (6) illustrate the algorithms which make up the PCP.

Each case in the CASE FILE has case identifying data, distressed unit data and reporting command data and resource data.

If the case is historically a multi-unit case, with multiple command reporting data, then the date and the time the case arrived to the system becomes the earliest time a Coast Guard station was notified of the case. This is the minimum value of the set of C1's, the date and time the reporting command was first notified, called MINC1. This Coast Guard station or the earliest reporting command becomes, for the time being, the primary station. (The primary is later recalculated in OPSIM EXEC as the closest of the set {P+A}, where P is the primary and A are its adjacents.)

If the case is a single-unit case then the reporting command becomes the primary again until modified by the OPSIM EXEC.

Those cases appearing on the C-130 TAPE must have their district identified prior to assigning a primary station. For each of these cases, the distance from the case location to the District Centroid of each district is calculated and that district corresponding to the minimum of these distances is assigned.

If no location is given for the cases appearing on the C-130 TAPE, then the district is assigned via the Monte Carlo of the

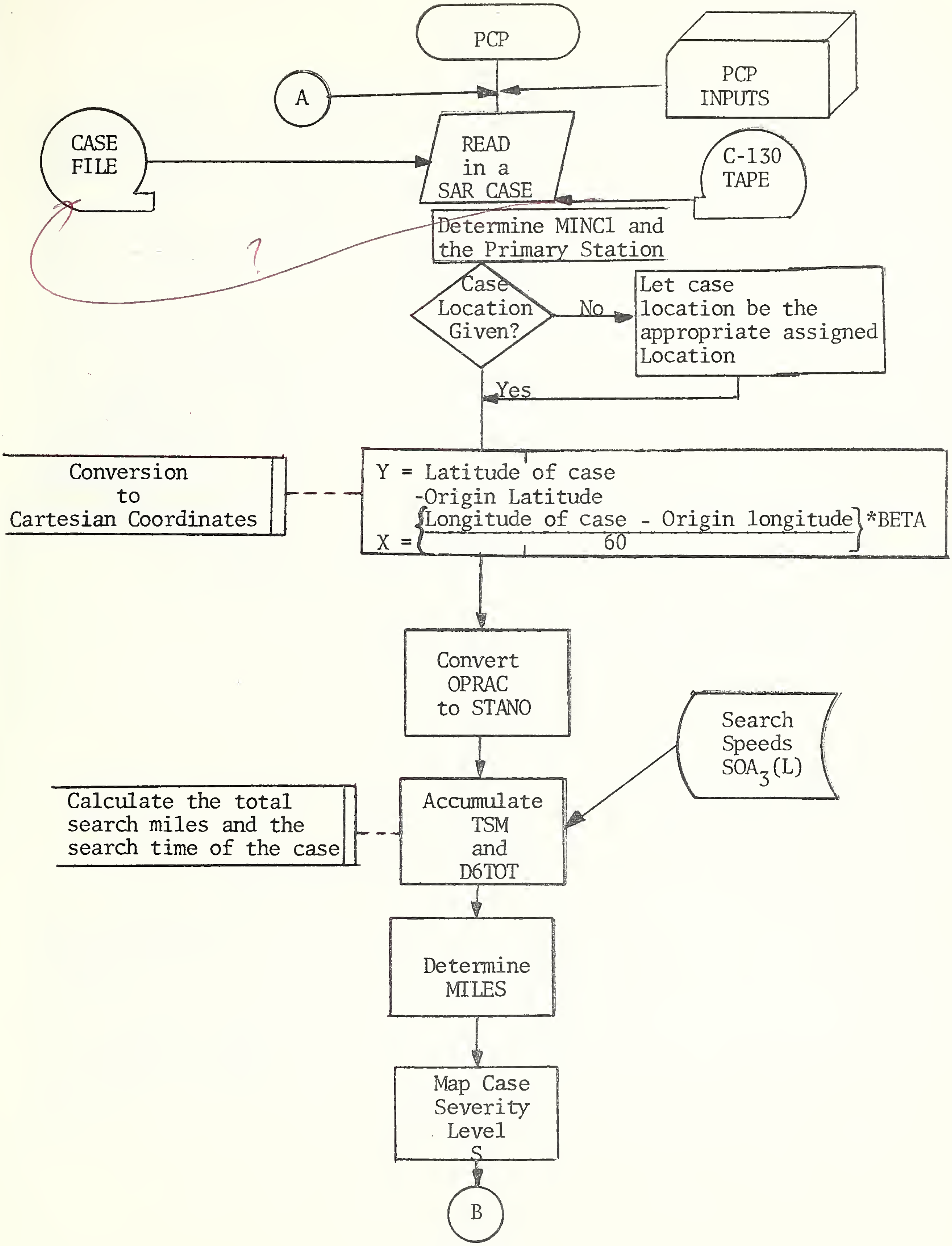


Figure 4
PCP Flow Chart

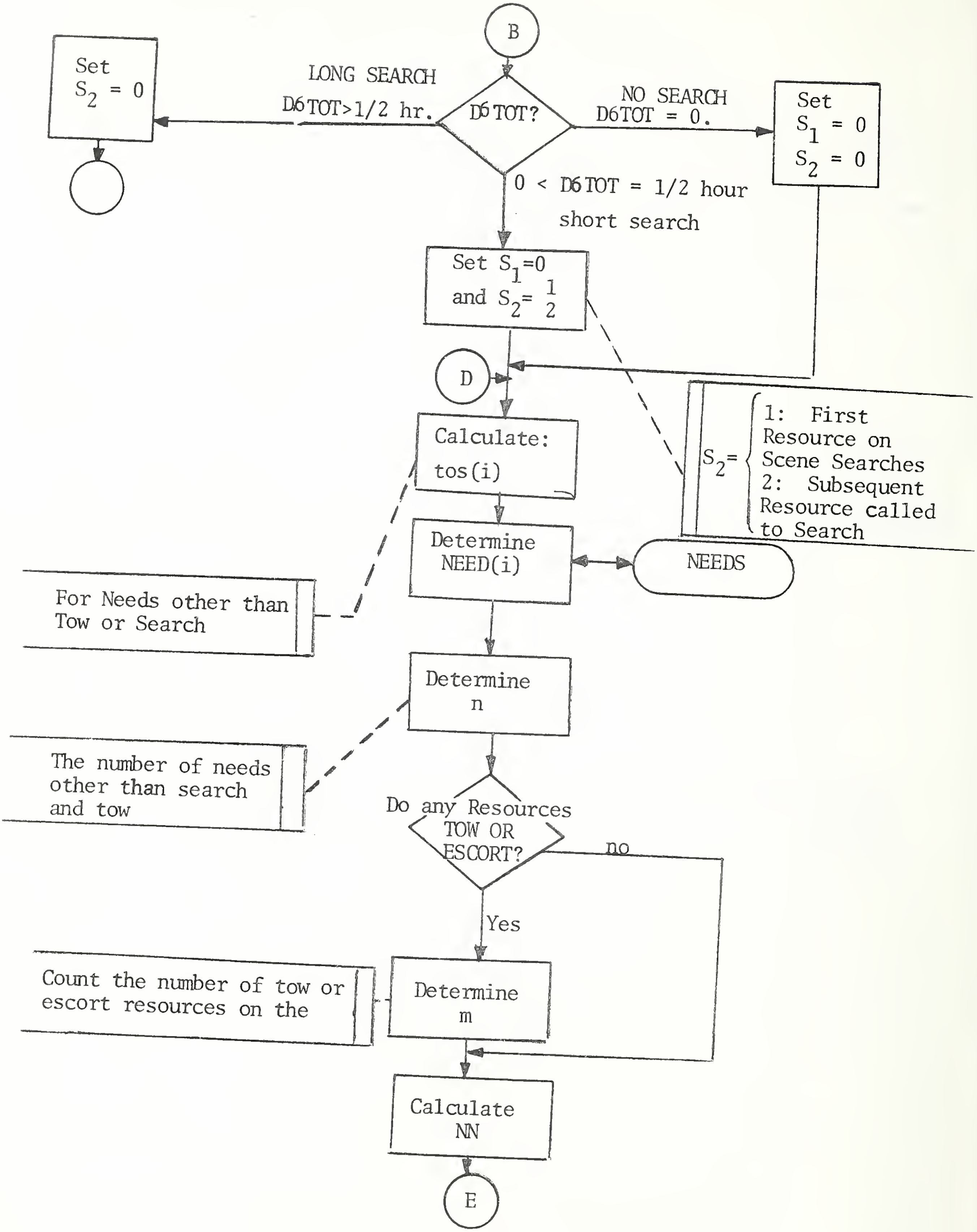


Figure 5

PCP Flow Chart (continuation)

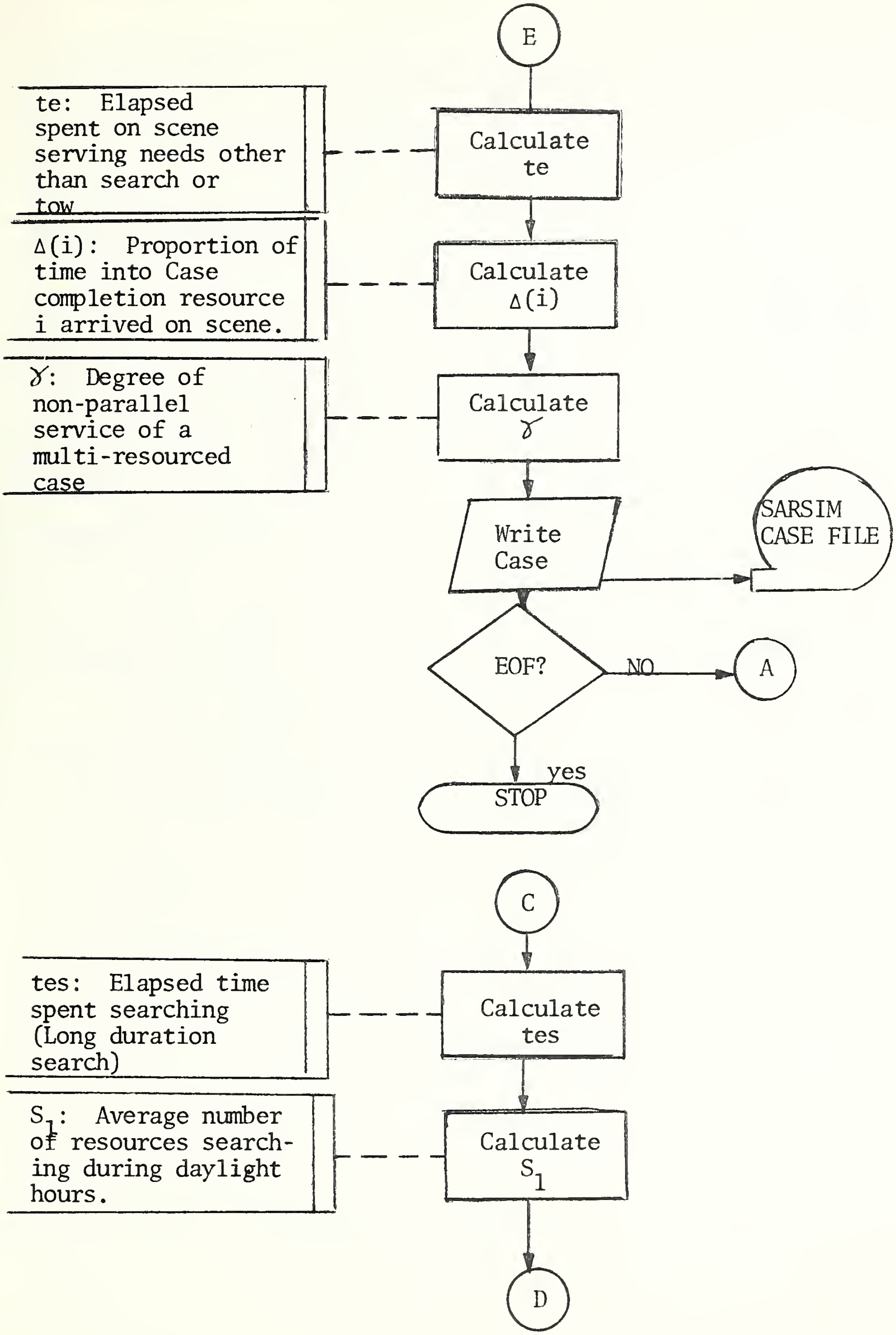


Figure 6
PCP Flowchart (Concluded)

district in accordance with an inputted frequency distribution of the C-130 cases across the districts of interest.

Once all the C-130 cases have been assigned a district, the primary station can then be determined. If the case has been assigned to a district other than the one being exercised, then the primary becomes the station at which the C-130's are based. (For example, on the East Coast, Elizabeth City would be assigned as the primary.) If the C-130 case occurs in the district being exercised, then no primary is assigned. Instead, if there is no primary, then OPSIM EXEC calculates the closest Coast Guard station in the district and assigns it as the primary.

For each case, its location (latitude, longitude) is converted to Cartesian coordinates, (x,y) relative to the district origin. (Origin Latitude and Origin Longitude.) Latitude and longitude are given in minutes. BETA is the length in nautical miles of a degree of longitude at the district origin.[3]

If the case has no given location, then a location is assigned some inputted distance from the primary. (This scheme is not used for those cases from the C-130 TAPE). Given that the primary, i, is located at Cartesian coordinates (x_i, y_i) from the district origin, then the case is assigned the location $(x_i + \Delta x, y_i + \Delta y)$. Both

---

[3] Bowditch, Nathaniel U. S. Government Printing Office, 1966 corrected print

Δx and Δy are user input, and hold for the entire district.

If the case is from the C-130 TAPE, and has no location, then the C-130 Case District Centroid is assigned, corresponding to the district either calculated or assigned as described above.

Next, the OPFAC identification numbers are replaced by a sequential station number, STANO, used in the simulation.

From the resource data records of a case, the total search time of the case, D6TOT, and the total search miles, TSM, are calculated by examining the hours spent searching and the resource type, L, that searched historically. That is,

$\text{D6TOT} = \sum_i \text{D6}(i)$, where, D6(i) is the hours spent searching by resource i; and,

$\text{TSM} = \sum_i \text{D6}(i) * \text{SOA}_3(\text{L})$, where $\text{SOA}_3(\text{L})$ is the search speed of the L^{th} type resource.

The variable MILES, the distance the distress is located off shore, is determined in the following fashion:

1. If the code for B16, the Type of Distress Area, indicates the case occurred less than a 1/2 mile off shore, then MILES = 0.3 miles.
2. If the code indicates the case occurred less than 5 miles off shore, but greater than 1/2 mile, then MILES = 3.0 miles.

3. If the code indicates the case occurred less than 10 miles off shore, but greater than 5 miles, then the distance is taken as 8.0 miles.
4. For values of B16 exceeding 10 miles, the distance is the value of B16. However, if B16 is unknown, then MILES = 10.0)

The severity, S, of the case is mapped in the following way in an attempt to model properly the higher urgency of responding to cases involving high danger to personnel. Thus, increasing values of severity will indicate increasing seriousness:

1. If the code indicates the value (1), i.e.,no immediate danger to personnel or property, it maps to a severity level for simulation purposes as a (1).
2. If the code indicates a (2), i.e.,moderate degree of danger to property, then it is mapped as a (2).
3. If the code indicates a (3), i.e.,moderate degree of danger to <u>personnel</u> and property, then it is mapped as a (4).
4. If the code indicates a (4), i.e.,serious, involving <u>property only</u>, then it is mapped as a (3).
5. Finally, if the code indicates a (5), i.e.,serious, involving personnel or personnel and property, then it is mapped as a (5).

Each case input to OPSIM requires indicators to determine if the client's location is unknown and a search must be conducted prior to serving any of his needs. A short search is characterized by a total search time, D6TOT, of one-half hour or less.[4] If the situation calls for a short search, it is performed either by the first resource on scene or by a single additional resource, called to scene by the resource first to arrive scene. From the resource data, the earliest resource arriving to the scene is examined to see if it historically performed the search. If so, then the total search task is assigned to that resource and if not, then an additional resource must have been called in, and the code for short search,S_2, is set to a 2.

If D6TOT exceeds a half-hour, then S_2 is coded as zero, and S_1, the average number of resources that searched for an extended period is determined next. (See Figure 5.) S_1 is defined as the ratio of the total resource time spent searching, D6TOT, to the daylight hours of search. This implies that the developed value S_1 represents the equivalent resources searching in parallel. To calculate S_1, the elapsed time spent searching on the case, tes, must be found. For each responding resource, i, D4FRST(i), the clock time resource i completed searching, is calculated as the sum of D4(i), the time resource i arrived on scene, and D6(i), the elapsed time resource i spent searching. The elapsed time, tes, becomes:

$$\text{tes} = \underset{i}{\text{MAX}} \{\text{D4FRST}(i)\} - \underset{i}{\text{Min}} \{\text{D4}(i)\}$$

---

[4] Although not parameterized, this value may be changed by a simple program modification.

Note tes includes the nighthours within the elapsed search time of the case; thus the nighthours, NH, must be calculated and subtracted from tes.

The hours of daylight are taken as 14 hours. If tes does not exceed 14 hours, then NH is set to zero. If tes is between 14 and 24 hours, NH becomes tes minus 14 hours. If, however, tes exceeds 24 hours, NH becomes tes/2.4 or the proportion of tes attributable to night time. A constant is added to the ratio to facilitate rounding up to the next whole resource. The brackets [ ] indicate truncation to the largest integer. Thus, S_1 is given by,

$$S_1 = \left[\frac{\text{D6TOT}}{\text{tes-NH}} + .99 \right]$$

where,

$NH = 0$, if $tes \leq 14$; or

$NH = tes - 14$, if $14 < tes \leq 24$; or

$NH = tes/2.4$, if $tes > 24$

Once all the search parameters are calculated for the case, the parameters relative to the serving of the remaining needs, including tow or escort (i.e. non-search), are determined next.

The time each resource spends on scene, tos(i), serving a need other than search, tow or escort is derived from the resource data. From the data base, the following information is used: D8(i), the total elapsed time spent searching; D3(i), the time the resource was underway; D4(i), the time the resource arrived on scene; and D9(i), the number of sorties. From the above, the expression for time on scene as becomes:

$$tos(i) = D8(i) - D6(i) - 2 * D9(i) * \{D4(i) - D3(i)\}$$

Corresponding to the time on scene is a specific need, NEED(i), for each resource participating on the case. Again,each NEED(i) is a service requirement other than search, tow or escort. Subroutine NEEDS is called to convert the historical assistance rendered to personnel (D11) and property, both primary (D12) and secondary (D13), to a single coded value required for each "need" (and for each resource) in OPSIM. These translations, the basis of NEEDS, are listed in Table 1. Note that some of the coded needs in OPSIM encompass a number of different types of assistance rendered. The reader is referred to Section III, of SRAS, and, in particular, the Resource Capability Matrix, for a description of those resources capable of performing these needs. Figure 7, Subroutine NEEDS, illustrates the decision process necessary to translate the assistance rendered (reported on each resource card) to a single need. D_1, the assisting resource type, is queried initially. Personnel aided by an aircraft preempt aid to property. If the assisting resource is an aircraft and D11 is positive, then the need becomes the translated D11. If D11 is zero, and D12 is positive, then D12 need is recorded. If both D11 and D12 are zero, then the need becomes 18, General Assistance Rendered.

Table 1

Assistance Rendered; Translation to Need

If D11 is:	Then the Need Becomes
Personnel in Position of Peril, Rescued or Assisted by:	
10: Attempted Rescued-Failed	16: Evacuate People
11: Boat or Vessel Pickup	↓
12: Amphibian Water Landing	↓
13: Helicopter Water Landing	↓
14: Helicopter Hoist	↓
15: Dropping/Providing Equip.	1: Provide Equipment
16: Aircraft Landing on Land	18: General Assistance Rendered
17: Vectoring Other Unit to Assist	5: Vector Other Unit
18: Personnel Assistance	16: Evacuate People
Medical Evacuation of Personnel by:	↓
30: Boat or Vessel Pickup	↓
31: Amphibian Water Landing	↓
32: Helicopter Water Landing	↓
33: Helicopter Hoist	↓
34: Diversion of Other Unit	5: Vector Other Unit
35: Vehicle or Personnel	18: General Assistance Rendered
36: Aircraft Landing on Land	↓
Medical Aid Rendered to Personnel by:	↓
40: Delivery of Doctor	↓

Table I (continued)

41: Delivery of Medical Supplies	1: Provide Equipment
42: Diversion of Other Unit to Scene	5: Vector Other Unit
43: Passing Medical Advice	18: General Assistance Rendered
44: Rendering First Aid	18: General Assistance Rendered
97: Recovered Bodies	16: Evacuate People
99: Unclassified	18: General Assistance Rendered

If D12 or D13 is:	Then the Need Becomes:
60: Attempted Salvage-Failed	14: General Assistance Rendered-Surface
61: Fought Fire	4: Fought Fire
62: Dewatered	6: Dewatered
63: Dewatered and Towed	15:[+] Tow; Dewatered and Towed: Refloated and Towed
64: Refloated	7: Refloated
65: Refloated and Towed	15:[+] Tow; Dewatered and Towed, Refloated and Towed
66: Towed	↓
67: Refueled or Resupplied	9: Refueled and Supplied
68: Escorted	*
69: Tugbird Tow	15:[+] Tow; Dewatered and Towed; Refloated and Towed
70: Delivered Pump by Vessel	2: Delivered Pump & Equipment

---

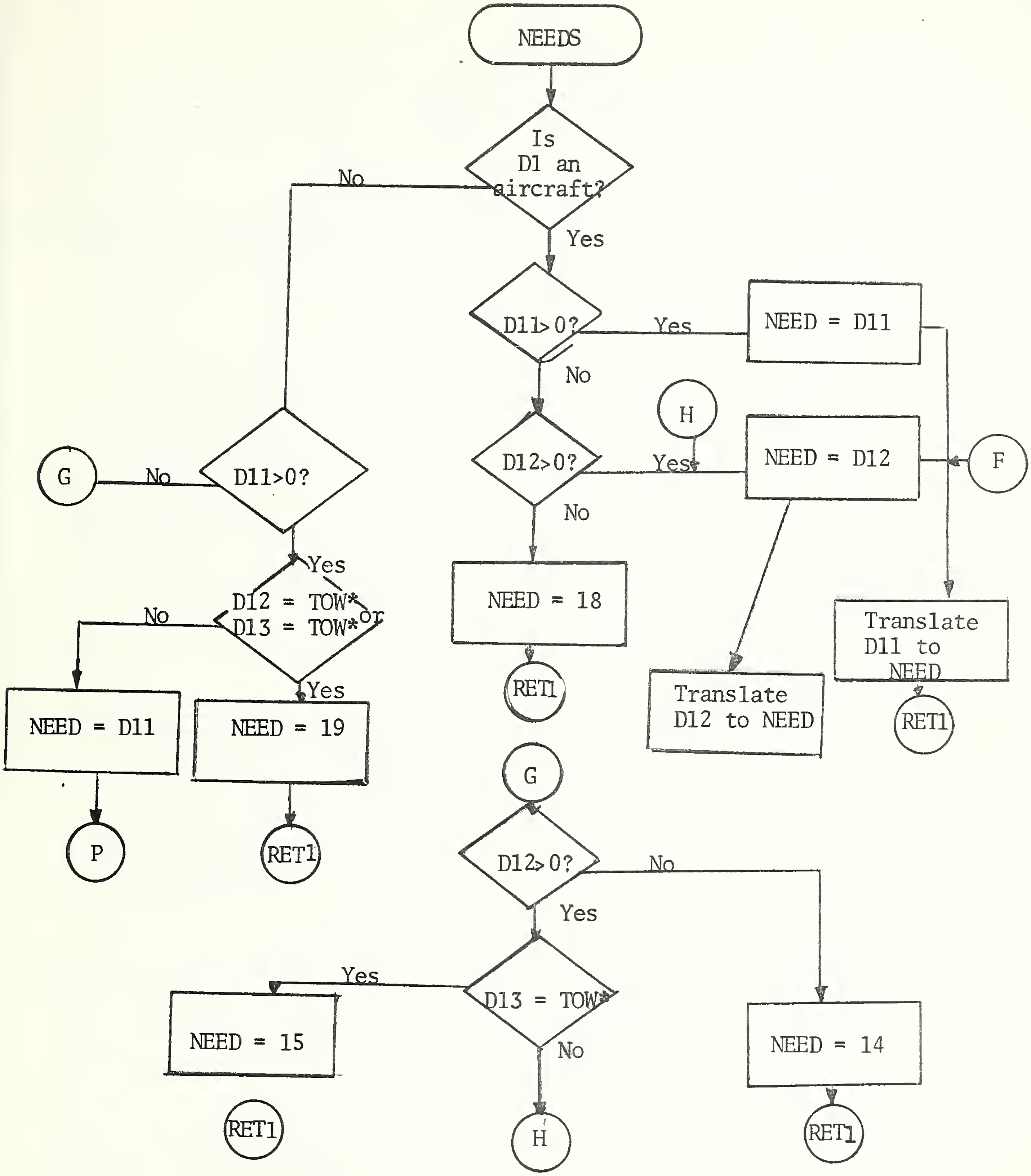
*Need is 10: Surface Escort, if B13 indicates distressed unit is not an aircraft.

Need is 17: Air escort, if B13 indicates distressed unit is an aircraft.

[+]or Need is 19: Rescue and Tow is D11 > 0 and D1 not an aircraft.

Table I (continued)

71:	Delivered Pump by Air	↓	
72:	Freed Vessel from Ice	8:	Icebreaking
73:	Freed Distressed Unit	13:	Freed From Position of Peril
74:	Made repairs	3:	Made Repairs
75:	Located Property and Advised Owner	12:	Located Property
76:	Recovered Property	15:†	Tow; Dewatered and Towed; Refloated and Towed
77:	Navigational Assist	18:	General Assistance Rendered
78:	Destroyed Menace to Navigation	14:	General Assistance Rendered-Surface
79:	Stood by	11:	Stood by
99:	Unclassified	18:	General Assistance Rendered



*TOW; Dewater & Towed; Refloated and Towed

Figure 7
NEEDS Flow Chart

If the assisting resource is not aircraft and D11 is greater than zero and D12 or D13 is tow, dewater and tow, or refloat and tow, then the need is coded as a 19, rescue and tow. If D12 or D13 is not a tow, dewater and tow nor refloat and tow, then assistance to personnel predominates, and the need becomes the translated D11 assistance rendered.

If the assisting resource is not an aircraft and both D11 and D12 are zero, then the need is coded as a 14, General Assistance Rendered. If D11 is zero but D12 is not, then D13 is queried. If D13 is a tow, dewater and tow, or refloat and tow, then the need becomes 15, tow, dewater and tow, or refloat and tow. If D13 is not a tow, dewater and tow, nor refloat and tow, then the need becomes the translated D12.

The total number of needs, n, is determined by accumulating the total number of resources other than those which searched, towed or escorted. The value m is the number of resources that performed a tow or escort. NN is determined according to those conditions presented previously in Section 2C on page [13].

In order to simulate the degree of parallelism in the service of a case, additional case parameters had to be extrapolated from the data base. First, the elapsed time spent rendering aid (other than search, tow, and escort), t_e, is found. For each resource i on the case, D4FRST(i) is calculated, as described previously. (Recall, D4FRST(i) is the time that resource i complete searching (if D6(i) were greater than zero) assuming search commenced immediately upon arrival on scene of resource i.) In addition, the time resource i completes searching for the client,(if any search was involved,) and servicing him, designated LVTM(i), is calculated as the sum of D4FRST(i) and tos(i). t_e can then be calculated thus:

$$t_e = \underset{i}{\text{Max}} \{\text{LVTM}(i)\} - \underset{i}{\text{Min}} \{\text{D4FRST}(i)\}.$$

Next, in order to schedule subsequent arrivals of resources to the scene of the SAR incident, Δ(i), the proportion of time into case completion resource i arrived on scene to serve need i, is found:

$$\Delta(i) = \frac{\text{D4FRST}(i) - \underset{i}{\text{Min}} \{\text{D4FRST}(i)\}}{t_e - \text{tos}(i)}$$

For the first resource on the case, Δ(i) is set to zero.

Finally, α, the degree of non-parallel service on a multi resource case serving needs other than search, tow or escort, is calculated as:

$$\gamma = \frac{t_e - \underset{i}{\text{Max}} \{\text{tos}(i)\}}{\sum_i \text{tos}(i) - \underset{i}{\text{Max}} \{\text{tos}(i)\}}$$

The reader is referred to the material on MRAS for a comprehensive discussion of Δ(i) and α.

Once, the case is completely processed, it is output on the SARSIM CASE FILE, the input to DEMGEN. When the end of file (EOF) is reached, that is all the cases on the CASE FILE and the C-130 TAPE have been processed, PCP halts.

It is stressed that the case attributes have been developed from the data base, i.e. the CASE FILE and the C-130 TAPE. Essentially the case is reconstructed on a time line, and partitioned into the general order of search, if required; service of needs, other than search, tow or escort; and, finally, tow or escort, if required. In re-constructing the case from the data, inconsistencies in the recording of the data have been overcome, so that the case is simulated as closely as possible to the historical past.

D. The DEMGEN Program

The main objective of DEMGEN is to prepare a chronological CASE TAPE* from the SARSIM CASE FILE, which was an output from the PCP. The user may choose whether the ordering should conform to past history, or whether randomness is to govern.

The first option, described in Volume III of this series as a separate program called HIST, recapitulates historical precedent. The user specifies inclusive dates of interest and DEMGEN creates a CASE TAPE listing the cases of a given district in the historical order of their occurrence during the period of interest, along with the appropriate case parameters. This provides a mechanism for simulating history, thereby enabling a comparison with simulation results for OPSIM with the corresponding historical outcomes. Valuable insights may thus be afforded into the simulation and validation processes.

---

*See footnote on page 36.

The user's second option is to have times of occurrence determined by random processes. This option may be applied separately to the cases occurring within the district and also to those historically served by C-130 aircraft.

This second option preserves the correlation between an individual case's attributes and its relative time of occurrence, i.e., the concept here supports the fact that certain kinds of cases occur at certain times of the year and are peculiar to the time of week and time of day. Specifically, the output from PCP retains the historical time of occurrence, and DEMGEN sorts these cases from the SARSIM CASE FILE by predesignated time periods. These time periods are:

1. Weekday Day cases in Peak season
2. Weekday Night cases in Peak season
3. Weekend Day cases in Peak season
4. Weekend Night cases in Peak season
5. Weekday Day cases in Non-Peak season
6. Weekday Night cases in Non-Peak season
7. Weekend Day cases in Non-Peak season
8. Weekend Night cases in Non-Peak season

Cases with all their attributes are stored in the computer according to these categories or "boxes". That is, there exists a file of cases for each of the above-listed time periods.

The arrival time of a case is generated by the Monte Carlo technique from a set of interarrival time distributions calculated from the historical times of occurrence. Inter-arrival times of the district have been assumed to be exponentially distributed. The concept of a set of these distributions attempts to model the changing arrival patterns over the day. More specifically, for each of the designated time periods, a distribution is developed for each hour in the time period. The parameter λ_{ij} represents the average arrival rate for the ith hour of the jth time period. This parameter is estimated by examining the number of arrivals in a given hour over the time period of interest for a given district.

For the random generation of case arrivals, a start time is given to initiate the generation of a CASE TAPE. Given the hour and date of the start time, a case is selected randomly from the proper file corresponding to the time period. (Since sampling with replacement is applied,the case is not removed from the file.) A random sample is then drawn from the proper interarrival time distribution, using that λ_{ij} corresponding to the i^{th} hour in the j^{th} time period. The reciprocal of this sample, Δt, represents the time from the start time to the next case arrival. Thus, the time the next case occurs is the start time plus Δt; this time, designated OCCUR, is the time the case arrives to the system or requests assistance. OCCUR is included as a case attribute and is output onto the CASE TAPE.

A new sample is drawn from the distribution corresponding to the time period of the latest OCCUR. The next time of occurrence of a succeeding case becomes the sum of OCCUR and the new Δt. From the proper time period file corresponding to this newly updated OCCUR, a case is then randomly drawn. The procedure is continued until the scenario limits have been reached, i.e., either the stop time of the simulation or a user input upper limit on the number of cases is reached.

It is desirable to prevent the generation of large interarrival times. This situation can occur quite frequently when the arrival rates (λ_{ij}) are small. Without any limitation, a small λ_{ij} could result in several time periods being bypassed, in which the λ_{ij}'s are greater than that λ_{ij} used to generate the long interarrival time. Two schemes are offered to the user to help prevent this from happening.

The first scheme limits the generation of interarrival times to $3/\lambda_{ij}$ hours, truncating the asymptotic tail end of the exponential distribution. (The cut-off, $3/\lambda_{ij}$ was chosen since this value represents approximately 95% of the area under the exponential distribution curve.) Thus, if the next interarrival time exceeds $3/\lambda_{ij}$ hours, OCCUR is updated to OCCUR + $3/\lambda_{ij}$ hours and the process continues with the new λ_{ij} corresponding to the new time period. Also, if any λ_{ij} is zero, then no arrival occurs and OCCUR is updated one hour and the new λ_{ij} is used to determine the time of the next arrival.

The second scheme checks for an arrival in every (i, j) interval, but does not guarantee an arrival in that interval. If the sampled interarrival time, Δt, exceeds 60 minutes, then a new sample is drawn. The process is continued until the sample drawn, Δt is no more than 60 minutes. Then the time of occurrence of this new case becomes:

$$\text{OCCUR (New Case)} = \text{OCCUR (Old Case)} + (n-1) * 60 \text{ minutes} + \Delta_t,$$

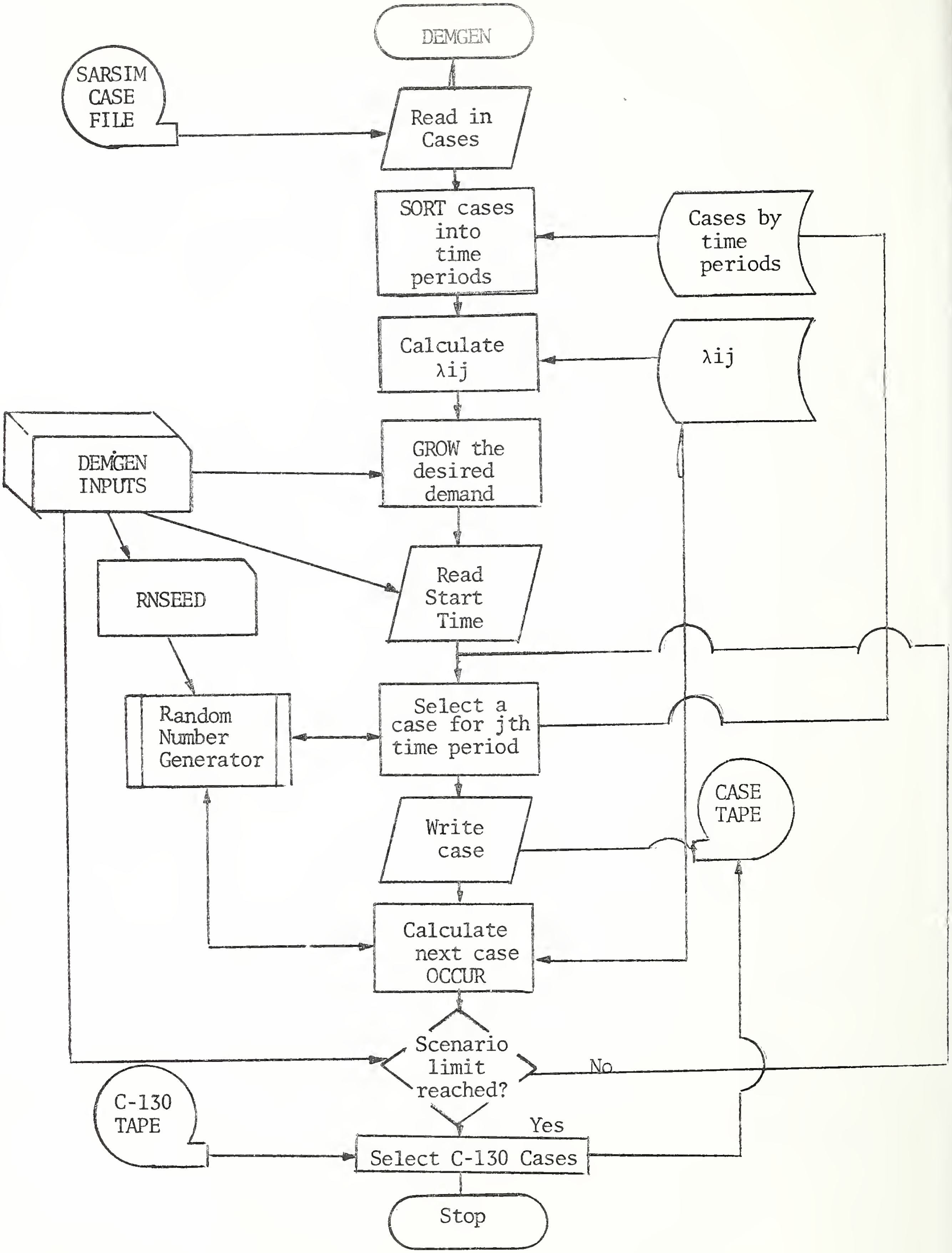
where n is the number of samples, and Δt is less than 60 minutes. Each time a sample is required, it is sampled from a distribution with the λ_{ij} corresponding to the interval currently being investigated.

A number of user options are offered to develop the desired CASE TAPE. For example, mechanisms are incorporated to accommodate the growth of cases via preselected logic switches if it is desired to increase the case population across all the cases by X%. Similarly, any set of λ_{ij}'s may be increased by X%, or any specific λ_{ij} can be increased by a given percentage.

For more specialized growth patterns involving particular OPFAC's and selected case parameters, e.g.,clientele type, the user can input his desired "IF" statements into the GROW routine. This software "grows" the cases randomly at the proper rate and inserts them in the proper files. This option allows the most flexibility (other than by hand selection) in providing the user a mechanism for creating a desired demand.

Figure 8 summarizes the DEMGEN operations. A random number seed, RNSEED, may be input by the user, if desired.

Once all the cases have been generated in accordance with the desired scenario, those C-130 cases in concert with this scenario are inserted chronologically with the cases already generated to produce the CASE TAPE, if the historical date option for C-130 cases is taken. Should it be desirable to merge a Scenario Tape with the CASE TAPE to produce the final DEMAND TAPE, this can be done by writing a simple merge routine. If no SCENARIO TAPE exists, the CASE TAPE obviously becomes the input to OPSIM.



DEMGEN Flow Chart - Figure 8

3. OPSIM - The Operational Simulator of SARSIM

Individual cases are processed through OPSIM using the data on the exogenous DEMAND TAPE supplied by PREPRO. If required, a long-search is simulated, followed by assignment of one or more resources to satisfy needs for services other than search. (It should be recalled that location, needs and other case parameters of simulated cases are based on historical occurrences.) The overall structure of OPSIM is included in Figure (2) on page 35.

The OPSIM EXEC first examines the parameters of the presented case before passing control to the appropriate subroutine. In addition, the OPSIM EXEC calculates the distance of the case from the historically-designated primary station and also from adjacent stations, choosing the closest of these as the primary station for the simulation: this is considered to be the station initially notified of the case and which has primary responsibility for responding. For those cases which historically had no primary station or a non-primary station, the OPSIM calculates the nearest possible primary station in the district.

If there is a single client need (other than search), control is passed to the Single Resource Assignment Subroutine (SRAS); the Multi Resource Assignment Subroutine (MRAS) is called if there are two or more needs to be satisfied. For each of these assignments, the service is simulated in the Service Subroutine (SS). After each case has had its needs satisfied, the Service Subroutine calculates summary statistics for the Standard Output. Long search, however, has specialized calculations, handled within the Search Assignment and Service Subroutine (SASS).

For the assignment of resources in SRAS or MRAS, OPSIM considers both:

(a) Case attributes, such as needs to be met, case severity, environmental factors, physical characteristics of the vessel in distress and its location; and

(b) Resource attributes, such as status, location, ability to satisfy the client's needs, ability to operate in the given environment, and cost factors.

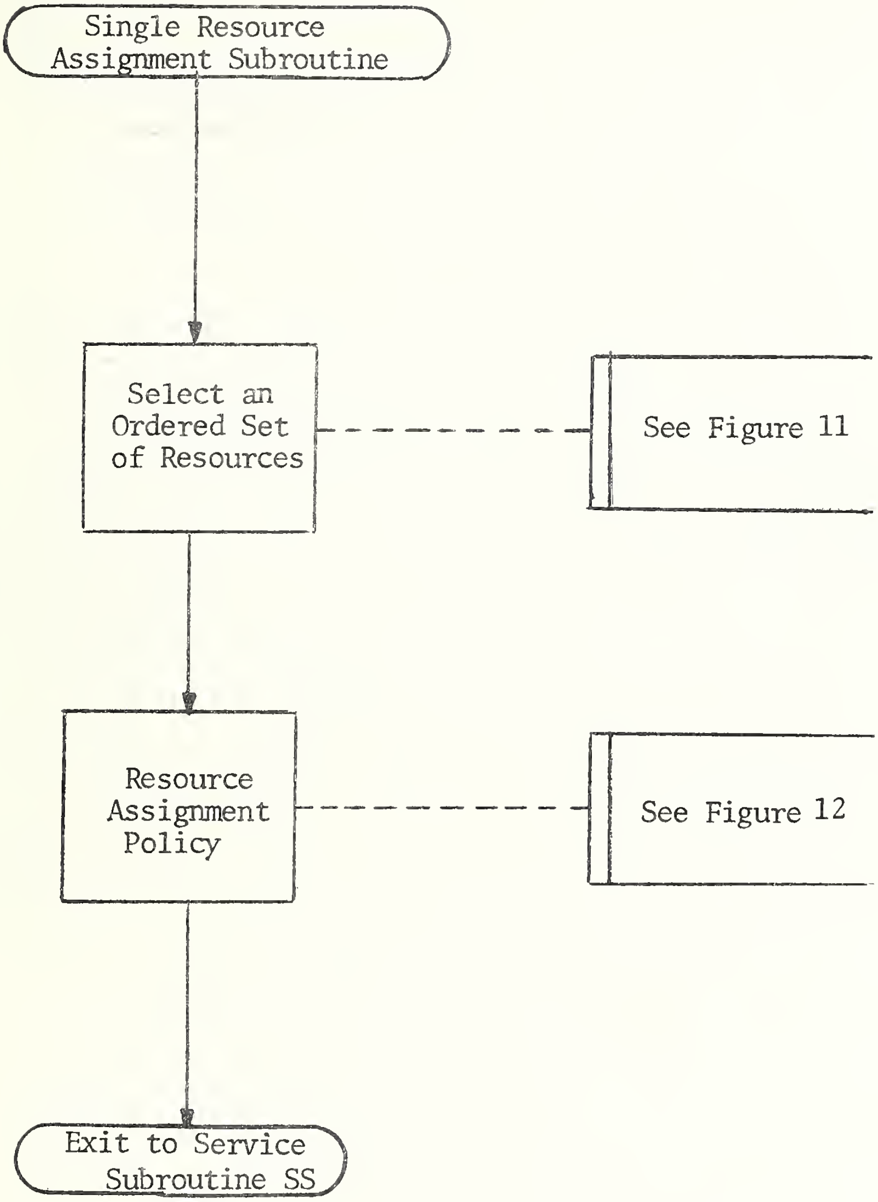
Resource selection in SRAS and MRAS is based on considerations of cost to vector a capable resource to the scene of the incident, time to transit to the scene, and case severity. In contrast, resource selection in SASS also entails consideration of the cost for a capable resource to cover the search area, the time required to cover, and severity conditions. For both search and the satisfaction of other needs, the set of resources eligible for consideration consists of those at the primary station and its adjacent stations, as well as the air stations and cutters covering the primary station.

The four major subroutines, SRAS, MRAS, SASS and SS, are described, in that order, in the sections which follow.

A. The Single Resource Assignment Subroutine (SRAS)

(1) General Description

A large fraction of SAR incidents are served by a single resource. For SARSIM, the Single Resource Assignment Subroutine (SRAS) forms an ordered set of capable resources which could satisfy a single-need case, The major steps are outlined in Figure (9). The ordering depends on the



Major Steps in the Single Resource Assignment Subroutine
Figure 9

time and cost of transiting to the scene for each considered resource, as well as policies for assignments prescribed by the user. In particular, "queue discipline" and "server discipline" must be specified to determine when service should be interrupted for cases of higher priority and the extent to which nearby stations interact with one another. Further details of assignments and service will be presented in a later section.

(2) Required Inputs

Some of the inputs required in the exercise of SRAS are supplied from PREPRO; others must be furnished by the user. The case attributes, from PREPRO, may be grouped as follows to show where, within the total simulation, they come into play:

(a) Operational Capability Factors, which determine whether a resource type is capable of servicing a particular need, depending on the values of the following attributes:

  (i) Location of the case
    a. Case coordinates
    b. Distance off shore
  (ii) Need(s) of the case (e.g., tow, dewater and tow, refloat and tow, evacuate personnel on board, provide equipment, deliver pump, make repairs, fight fire, etc.)
  (iii) Type of distressed unit
  (iv) Length of distressed unit
  (v) Number of personnel on board distressed unit
  (vi) Sea swell
  (vii) Wind

- (viii) Visibility
- (ix) Air Temperature

(b) Supplementary Factors - Case attributes (i) and (ii) below affect the Operational Simulator; (iii) and (iv) provide additional information for the Postprocessor.

- (i) Time of occurrence, OCCUR
- (ii) Severity of the case, S.
- (iii) Nature of distress (case type)
- (iv) Value of the vessel

The user must specify the following inputs to OPSIM for each simulation run:

(c) Station Inputs - For each station in the district:

- (i) Location of the station
- (ii) A list of the station's "feasible" adjacent stations, that is, those stations adjacent to the primary station (including surface patrol areas) with resources that might be sent to serve a case in the operating area of the primary station.
- (iii) A list of the aircraft stations and responsible cutters. (Responsible cutters are handled exactly like stations in that a cutter is a station in itself which can serve cases in the primary station's area.)
- (iv) Station's Resource Matrix, including the number of each resource type attached to the station; initialization status data ,i.e., busy or idle; and location.

(v) Crew Manning Level as it varies over the day and day of week and the crew level at which a standby is called.

(d) Resource Type Inputs

For each resource type, the following inputs are required from the user:

(i) Resource Capability Matrix - This matrix, prepared by the user in binary code, indicates the capability of each resource type to respond to a case for each operational capability factor and environmental factor permitted. Figure 10 illustrates the form of this matrix. Capability is assessed as being full 1, or absent, 0, relative to each case attribute. Figure 10 is presented for illustrative purposes only; these assessments can be varied by the user.

(ii) Resource Reliability - For each resource type, a coefficient defines the probability of "failure" immediately prior to assignment. Failure may result from unexpected malfunction, inoperability due to planned maintenance, or both.

(iii) Resource Speeds of Advance - For each type of surface resource, the speed can be modified as a function of sea swell. For air resources, modification for wind was considered unnecessary. The resource speed of advance is used to calculate the time for a resource to vector to the scene.

FIGURE 10
RESOURCE CAPABILITY MATRIX

CASE ATTRIBUTES	UTB (L) 40'	UTB (M) 30'	UTB (U) 17'	MLB 44/52	MLB 36	MRB/MSB	WPB 95	WPB 82	WYTM/WYTL	WMEC	WHEC	C130	HU16E	HH52A	HH3F
Swell															
0-5'	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5-10'	1	0	0	1	1	0	1	1	0	1	1	1	1	1	1
10-20'	0	0	0	1	1	0	1	1	0	1	1	1	1	1	1
20'	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Wind															
< 60 Kts.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
> 60 Kts.	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Visibility															
< 1/4 Mile	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
1/4 - 1/2 Mile	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1
> 1/2 Mile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

FIGURE 10 (continued) (2)

Air Temperature															
< 20°	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1
> 20°	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Visibility Offshore															
0 - 1/2 Mile	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1
1/2 - 5 Miles	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5 - 10 Miles	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
10 - 20 Miles	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1
20 - 50 Miles	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1
> 50 Miles	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
NEED AND RELEVANT FACTORS															
Provide Equipment	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Delivered pump/ Equipment	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Made Repairs	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Fought Fire	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Vectored Other Unit	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dewater	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

FIGURE 10 (continued) (3)

Refloated	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Icebreaking	0	0	0	1	0	0	1	1	1	1	1	0	0	0	0
Refueled & Resupplied	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Escorted	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Stood by	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Located Property & Owner Advised	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Freed from Position of Peril	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
General Assistance Rendered(Surface)	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Tow, Dewater & Towed, Refloated & Towed															
0' -30'	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
30'-65'	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0
65 -100'	1	0	0	1	0	0	1	1	1	1	1	0	0	0	0
100-200'	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0
> 200'	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
Evacuate (Rescue (POB)															
0 -5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

FIGURE 10 (continued) (4)

5 -10	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1
10-18	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0
18-25	0	0	0	1	1	0	1	1	1	1	1	1	0	0	0
> 25	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0
Air Escort	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
General Assistance Rendered	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rescue & Tow	1	1	1	1	1	1	1	1	1	1	1		0	0	0

(A search speed is also included for each resource type, to be used in the search routine, SASS).

(iv) Resource Operating Cost - This is the dollar cost per hour for operating each resource type and is used to calculate the cost for each resource to vector to the scene for subsequent ordering of resources.

(v) Resource Type Ranking - This is a relative (ordinal) ranking among the resource types by some user-determined cost. It can be used in lieu of operating cost in the final ordering of resource types prior to assignment.

(vi) Resource Underway Time - This is the time for a particular resource type to get underway from its homeport. (Note: resources on patrol should have no underway time, or start-up time. Small boats and aircraft may have a short time to get underway, but larger surface resources may require several hours.) DLAY(L) for the L^{th} resource type is input.

(e) Tolerance Time - This reflects the maximum acceptable waiting time for a client, measured from first notification of the incident. For each severity level, S, a time, TOL(S), is input. (If possible, assignments will be made for resources which can arrive on scene within the limits set by TOL(S).)

(f) Resource Assignment Policy - The user chooses from a set of resource assignment policies, each of which describes a preferential ordering of the desirability of calling an adjacent station and the desirability of interrupting another case. These policies define the server discipline in the simulation.

(3) SRAS Logic

When a single-need case is processed in OPSIM, control passes to SRAS and, subsequently, to the preselected resource assignment policy (RAP). The Service Subroutine (SS) is executed to simulate client service time and resource service time. (SS is discussed in a later section.)

Figure 11 shows the flow of operations of the first major step in SRAS, selecting an ordered set of capable resources. Figure 12 illustrates one of the resource assignment policies. It may be helpful to refer to these flow charts during the ensuing discussion.

(a) Selecting an Ordered Set of Capable Resources to Service a Case. Briefly, the problem of selecting an ordered set of capable resources is accomplished by considering the case's attributes, the resource's capability to satisfy the case's requirements, the relative distances between candidate resources and the case, the cost involved in vectoring each resource and the time for the resource to get underway.' Figure 11 indicates the flow of operations.

Step 1: The first step is to determine those resource types which are capable of serving the case. The Resource Capability Matrix (Figure 10)is accessed for the appropriate rows corresponding to applicable value for each of the case's attributes. These rows are then "ANDed" by the Boolean operation, and the result, a binary list, indicates capable resources. A zero indicates that the resource is incapable of serving this case; a one indicates capable resources. A zero indicates that the resource is incapable of serving this case; a one indicates capability.

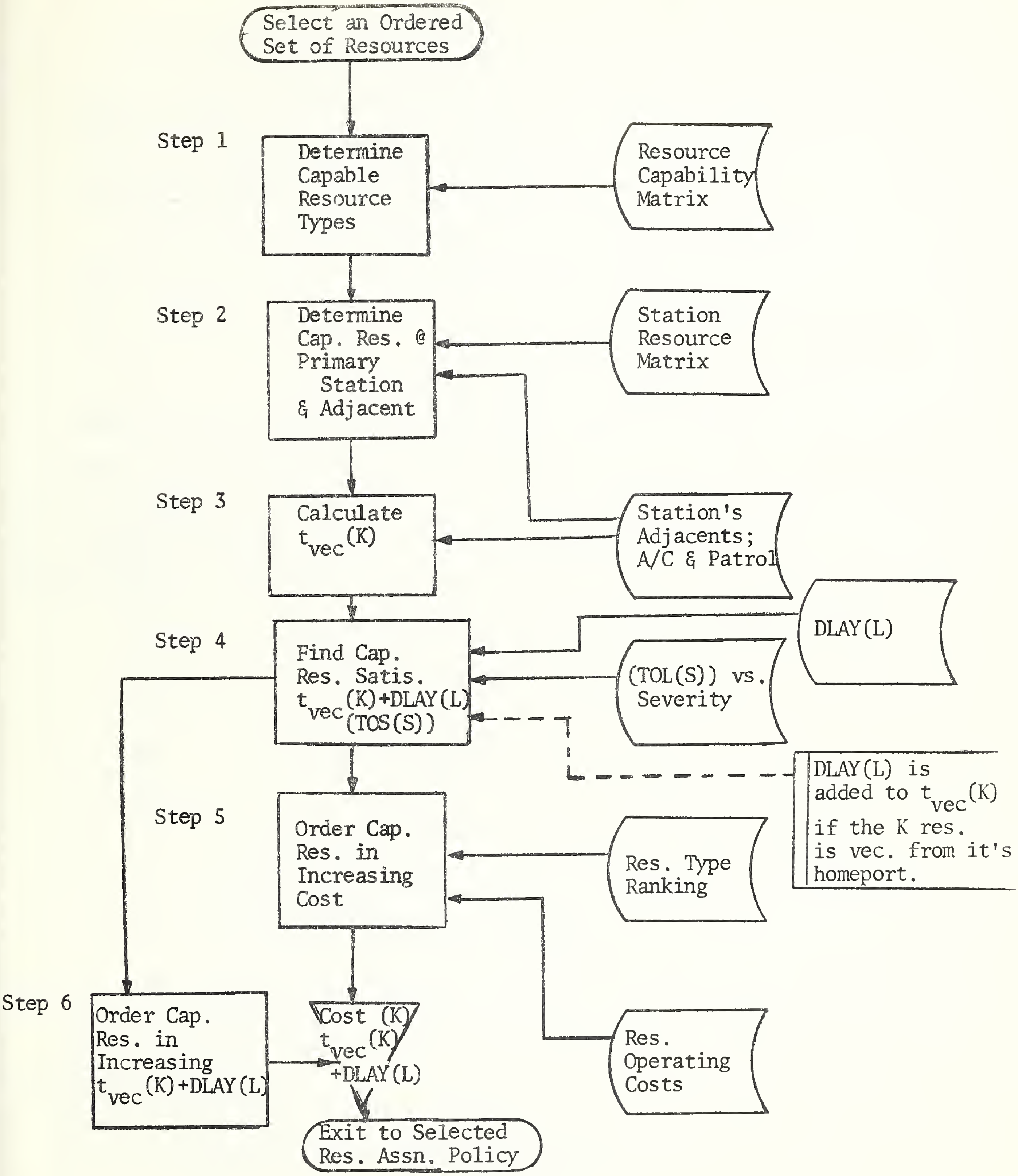
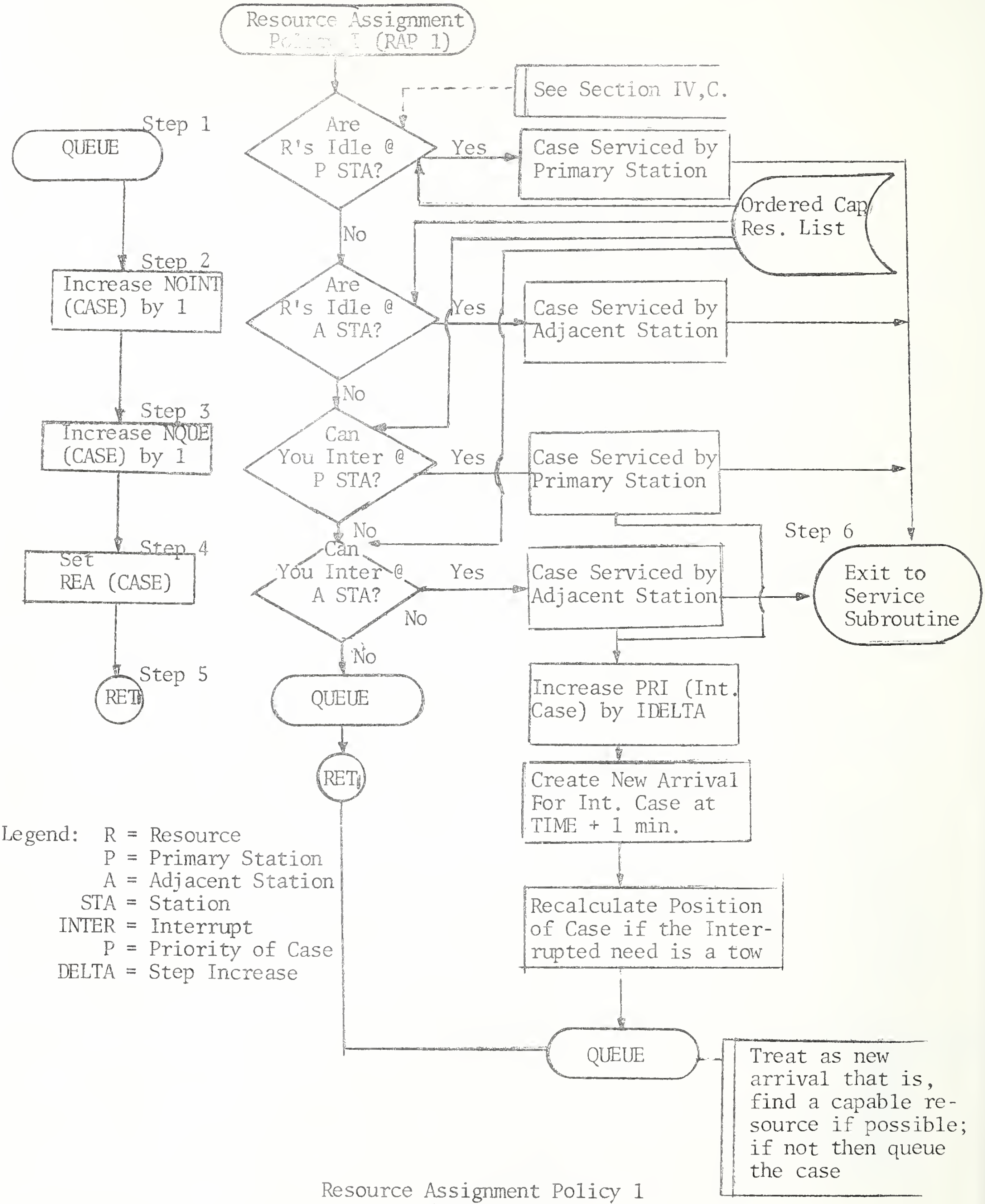


Figure 11
Select An Ordered Set of Capable Resources



Legend: R = Resource
P = Primary Station
A = Adjacent Station
STA = Station
INTER = Interrupt
P = Priority of Case
DELTA = Step Increase

Resource Assignment Policy 1
(RAP 1);
Queuing Routine
Figure 12
Modeling the Assignment of a Resource to Service Case

To illustrate, consider the following case: A 42' boat with 3 people on board requires a tow from 15 miles offshore. The environmental conditions include air temperature of 68°, visibility beyond a 1/2 mile, wind at 20 knots, and swell of 6'.

From the Resource Capability Matrix, the appropriate rows are selected (rows 2, 5, 9, 11, 15, 33, 37). Now, "ANDing" these rows, the result is:

1 0 0 1 1 0 1 1 0 1 1 0 0 0 0

Interpreting this result, we find that the resource types which can serve the case include:

UTB (L)
MLB (44 & 52)
MLB (36)
WPB 95
WPB 82
WMEC
WHEC

Step 2: The second step is to retrieve from the Station Resource Matrix for the station, its adjacents, its covering aircraft and patrol boats, those resources corresponding to the capable resource type list. It should be noted that the station referred to above is also a case attribute, and is, therefore, known at the time the case enters SRAS. This station does <u>not</u> necessarily answer the case. It is used as a mechanism for identifying a subset of resources within the entire district, which could answer the case. The result is a list of capable resources which are within "answering" range.

Step 3: Using the location of the case and the locations of the capable resources found in step 2, the time it takes each resource in the list to vector to the expected location of the case, $t_{vec}(K)$, is computed.

Step 4: Since the case enters the system with a given severity, S, the tolerance, TOL(S), can be compared to $t_{vec}(K)$ + DLAY(L), where $t_{vec}(K)$ is calculated in step 3 and DLAY(L) is retrieved for each resource (if at homeport). If there are no $t_{vec}(K)$ + DLAY(L) which are less than or equal to TOL(S), then step 5 is executed. Note: DLAY(L) is used only if the resource is to be vectored from its homeport to the expected case location.

Step 5: The capable resources for which $t_{vec}(K)$ + DLAY(L) does not exceed TOL(S) are ordered by increasing cost. The resources which cannot meet the TOL(S) criteria are ordered on increasing $t_{vec}(K)$ + DLAY(L). These two lists are then merged, first by cost and then by time. As part of the design, the user is offered two methodologies for ordering capable resources. It may be recalled that the user may opt for calculating the cost for each capable resource to get underway and vector to the expected location of the case, with the result used in the ordering process; alternatively,he may choose the resource type ranking to order the capable resources. The selection of the methodology is under use control. Once the ordering has been completed, the preselected resource assignment policy is then executed with this final ordered capable resource list.

Step 6: This step is entered if no resources satisfy $t_{vec}(K) \leq TOL(S)$. The capable resource list from step 3 is ordered on increasing $t_{vec}(K) + DLAY(L)$. Cost is not a factor in this situation.

(b) Resource Assignment Policies

These policies offer the user the opportunity to select a set of rules which govern the operational procedure, at the primary station, in calling for assistance from its adjacents, covering aircraft and cutters. (Covering aircraft and cutters can be included for every station, primary or adjacent.) These plans offer a wide diversity of operations, from pure station autonomy to an interactive station grouping policy. In addition, these policies offer the user the opportunity to test various interrupt rules in the resource selection process.

Each policy contains a decision block which ascertains the status of a capable resource, busy or idle; this also considers crew availability. If a crew is not available, the resource cannot be assigned. More precisely, this decision block could be entitled "Is there an idle resource and an available crew?" This block will be discussed further in a later section.

Basically, each policy assigns an idle capable resource with an available crew to the incoming case. Some policies allow the interrupt of a busy resource if the incoming case's priority is higher than those cases already being served.

A policy is preselected through the user inputs, and is called via a logic switch. Using the logic switch scheme, additional plans can be designed, added, and offered to the user. Policy 1 is detailed here in the text as an example . The additional plans offered are outlined in the text below.

(i) Resource Assignment Policy 1 (RAP 1)

Policy 1 considers the idle resources at the primary and adjacent stations sequentially, then considers interrupting busy resources at the primary and adjacents sequentially if the new case has a higher priority than those cases already undergoing service by these stations. Figure 12 shows the logic of this policy.

Step 1: Examine the idle resources, R's,at the primary station, P. (Primary includes covering aircraft and cutters.) Select the first idle resource from the Ordered Capable Resource List. Proceed to Step 6 for service of the case.

Step 2: If there are no idle resources at P, examine the idle resources at all of P's adjacent stations. Select the first idle resource at the adjacent stations, A, from the Ordered Capable Resource List. Proceed to Step 6 if one is found.

Step 3: If there are no idle resources at either P or A, and if the case has a higher priority than those cases being served at P or A, then interrupt a busy resource at P, serve the case in step 6, and queue the interrupted case. (The wait time in the system of the interrupted case and his interrupt count are updated for output purposes.) The interrupted case is treated as a new arrival to the system by subroutine QUEUE, which queues the interrupted case, (if possible another capable resource is located to serve the interrupted case.) QUEUE updates and records the following information for output purposes:

a. NOINT: The number of times interrupted.
   NQUE: The number of times case enters a queue.
   REA: The (first) reason for being placed in the queue.

PRI, the priority of the case is increased by IDELTA (user input) to give some preference to interrupted cases.

Step 4: Step 4, at A, is analogous to step 3 at P; it is executed if either an idle resource cannot be found at P or A, or a busy resource cannot be interrupted at P. If a resource cannot be interrupted at A, proceed to step 5.

Step 5: Queueing the case delays the start of the service of a new case or prolongs an interrupted case. A case is served when a capable resource becomes idle via EXQ subroutine. If the arriving case is of lower or equal priority than others undergoing service, it must wait for a capable resource to become idle. A non-interrupted queued case retains its original arrival time to the system. The interrupted queued case takes the time of interrupt as its arrival to the system. (This, in effect, causes the simulation to find an idle capable resource for the interrupted case.)

Step 6: Control is passed to the Service Subroutine (SS) once the resource has been assigned. The elapsed times for the resource to get underway, vector to the case, serve the case and return are simulated in this routine.

(ii) Additional Resource Assignment Policies

Most of these policies model a number of "server disciplines," such as a queue discipline other than priority interrupt. These policies range from complete station autonomy to station grouping.

a. RAP 2: This policy, considered to be similar to the current operational procedure, examines the idle resources at P; considers interrupt at P; examines idle resources at A; considers interrupt at A; queues the case or the interrupted case; exits to SS. Briefly, the steps are: P; P Interrupt;A; A Interrupt; Queue.

b. RAP 3: This policy groups the primary station P, and the adjacent stations A. The steps are: (P + A); (P + A) Interrupt; Q.

c. RAP 4: This policy models station autonomy in that the primary P is considered alone. The steps are: P; P Interrupt; Q.

d. RAP 5: This policy considers no interrupt and station autonomy. Priority ordering is allowed in the queue. The steps are: P; Q.

e. RAP 6: This policy is only applicable for multi-resource and search cases. The steps are: P; A; Q. This is further described in the MRAS documentation.

Note, a simple first-in first-out (FIFO) queue discipline can be modeled within each policy by letting the priority of all cases take on the same value. This could be done with a minor modification to PCP in PREPRO.

(c) Resource Idle and Operational and Crew Availability (RIOCA)

Within each resource assignment policy, the question of idle resource occurs at the primary station in resource assignment policies 1, 2, 3, 4, 5 and at the adjacent stations in policies 1, 2, 3 and 6. This takes into account the operational status of the resource and the availability of the crew. That is to say, when the ordered capable resource list is queried, in the preselected resource assignment policy, the question of on-line failure of the resource type and crew availability at the station to which the resource is attached, is also asked. (See Figure 13 for the flow of operations.) If the resource is idle, control passes to the assessment of operability of the resource, step 1. This is accomplished via Monte Carlo and comparison of the sample with the resource's reliability coefficient. Reliability is a function of resource type.) If the resource is operational, control passes to step 2, which queries the crew status at the station to which the resource is attached. If a crew is immediately available, the crew is assigned to the resource and the resource is assigned to the case. A call to subroutine SS is then made. If the crew is not immediately available, a standby crew is called

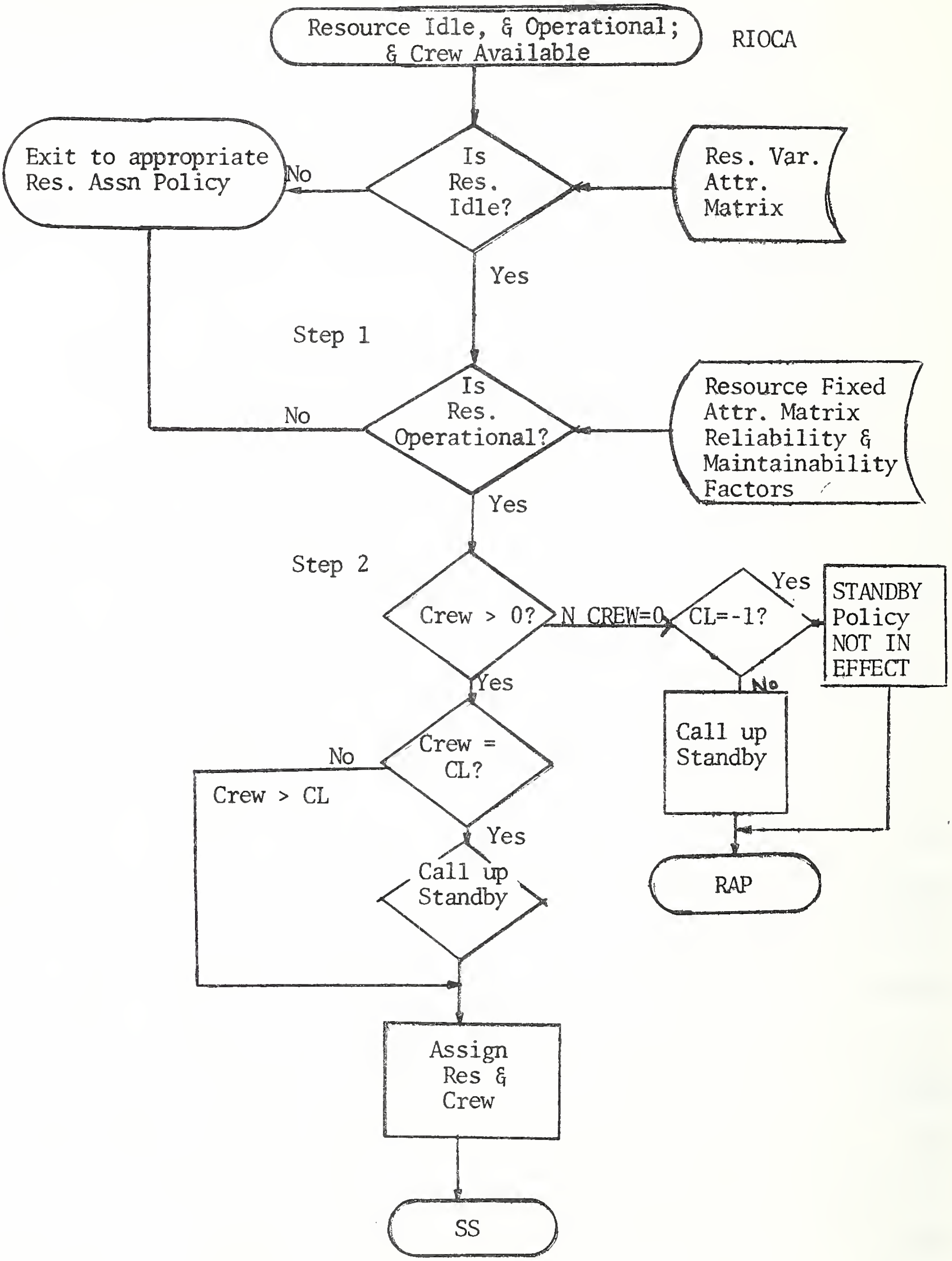


Figure 13
Resource Idle & Operational; Crew Availability (RIOCA)

up with a given delay time (if provided for by the user). If the resource is not idle or if the crew is not available, control is passed back to the preselected resource assignment policy, RAP, where an attempt is made to find a capable resource at the primary (or adjacent) station (depending on the RAP). Again, an available crew is also sought in RIOCA along with a determination of the resource's status and operability.

The user of the simulation is offered the option of including the policy of calling up a crew which is on standby by means of a set of codes for the variable CL. If CL is set to -1, the user excludes the policy of call up. If the user selects 0 or 1 for the value of CL, then a standby crew is called when the number of crews available (and not busy) reach the preselected level, 0 or 1. Checks are included in the program so that only a single standby is called per case.

B. The Multi-Resource Assignment Subroutine (MRAS) of OPSIM

(1) General Description

This section describes the assignment and scheduling of resources to aid those SAR cases with two or more needs, exclusive of the requirement for search. (Assignment of resources for the search need is simulated in SASS, described in Section 3C, beginning on page 101.) The Multi-Resource Assignment Subroutine (MRAS) may simulate the assignment of two or more resources from a single responding station, as well as resources assigned from two or more responding stations.

Resource assignment in MRAS is based on such case attributes as client's needs, case severity, environmental factors, physical characteristics of the unit in distress, and case location. In addition, resources are examined on the basis of their capability to serve the case needs, ability to operate under the environmental conditions, and the status, location and cost of each resource.

Paralleling the dynamics of search and rescue, clients are served in the simulation in the following general order of need: if required, the client is located through search; any needs beyond search are served on scene, if possible; finally, if required, the client is towed or escorted. Multiple services other than hand-off tows and escort may be performed simultaneously, in sequence, or some intermediate combination of series and parallel operations.

To minimize scheduling problems for several resources to serve multiple needs other than search or tow, the simulation treats each need of a multi-resource case as a new arrival into the system. This is equivalent to converting a multi-resource case into a set of single resource cases, each one with an associated arrival time and service need. Details of scheduling are provided in section (3) of MRAS, below.

Two difficult problems arose in MRAS with regard to distinguishing between single and multiple needs. On the one hand, there are operational situations where resource selection is based on the capabilities of a single resource to service several needs. Conversely, a single need may be partitioned so that several resources must be assigned to service it. This latter problem is posed, for example, when several resources are sent to fight a major (but single) fire.

To facilitate the handling of the first type of problem, multiple needs served by a single resource were treated as a single need in the simulation. The partitioning of a need to justify assigning several resources was not modeled; rather, a one-to-one correspondence exists between the number of resources historically assigned to the case and the number of needs simulated in OPSIM.

Since the multi-resource case is basically a set of single resource cases with associated needs, MRAS utilizes the fundamental logic of the Single Resource Assignment Subroutine (SRAS). An ordered set of capable resource types for each need of the case is found, as in SRAS; a resource is assigned from this set according to a strategy selected by the user, or in the case of station autonomy by setting a user switch. Each strategy defines the "queue discipline" (e.g., priority interrupt) and "server discipline" (e.g., level of station interaction).

Each multi-need case is first partitioned into a set of single resource cases. A subroutine then creates the associated arrival times for each member of this set according to the time required on scene to serve the need, and the degree of parallel service of the needs of the case. The initial arrival of the case to the system is preserved for the first need.

Each case has an ordered set of needs, created in PREPRO. Conditionality of needs is preserved partially by the macroscopic ordering approach to handling the case's search requirement, its needs beyond search, and, finally, the tow or escort need, if necessary. However, the needs other than search, tow and escort are considered independent, and no hierarchcal order is preserved except that they may be ordered in time, according to the case history. To explain, those needs other than search and tow (or escort), which are treated independently, can be queued in the simulation and served out of historical order.

During the service of a multi-resource case an attempt is made to provide continuous coverage of the client. This is simulated in the Service Subroutine, SS, but cannot be guaranteed should a case with higher priority arrive to the system and preempt a multi-resource case being covered.

(2) Required Inputs to Operate MRAS

MRAS inputs are essentially the same as those for SRAS. A few additional case attributes are generated in PREPRO especially for multi-resource cases. These include:

(a) The degree of non-parallelism in servicing the particular multi-resource case, (γ).

(b) The proportion of time into case completion the subsequent resources commence service, ($\Delta(i)$).

(c) The on scene time for each need except search, tow or escort ($tos(i)$).

(d) The primary station - the Coast Guard station receiving the distress call (as determined in PREPRO).

The user inputs remain the same as in SRAS, but also include a switch (INTRAP) to override the preselected resource assignment polic;y. In addition, the hand-off distance for tow (or escort) cases (HO) must be input. HO is the minimum hand-off distance from shore for the tow (or escort) situation. The assumption is made that hand-offs occur at a distance HO or greater from the tow (or escort destination), thus preventing the larger resource from towing (or escorting) into waters not safe for its navigation.

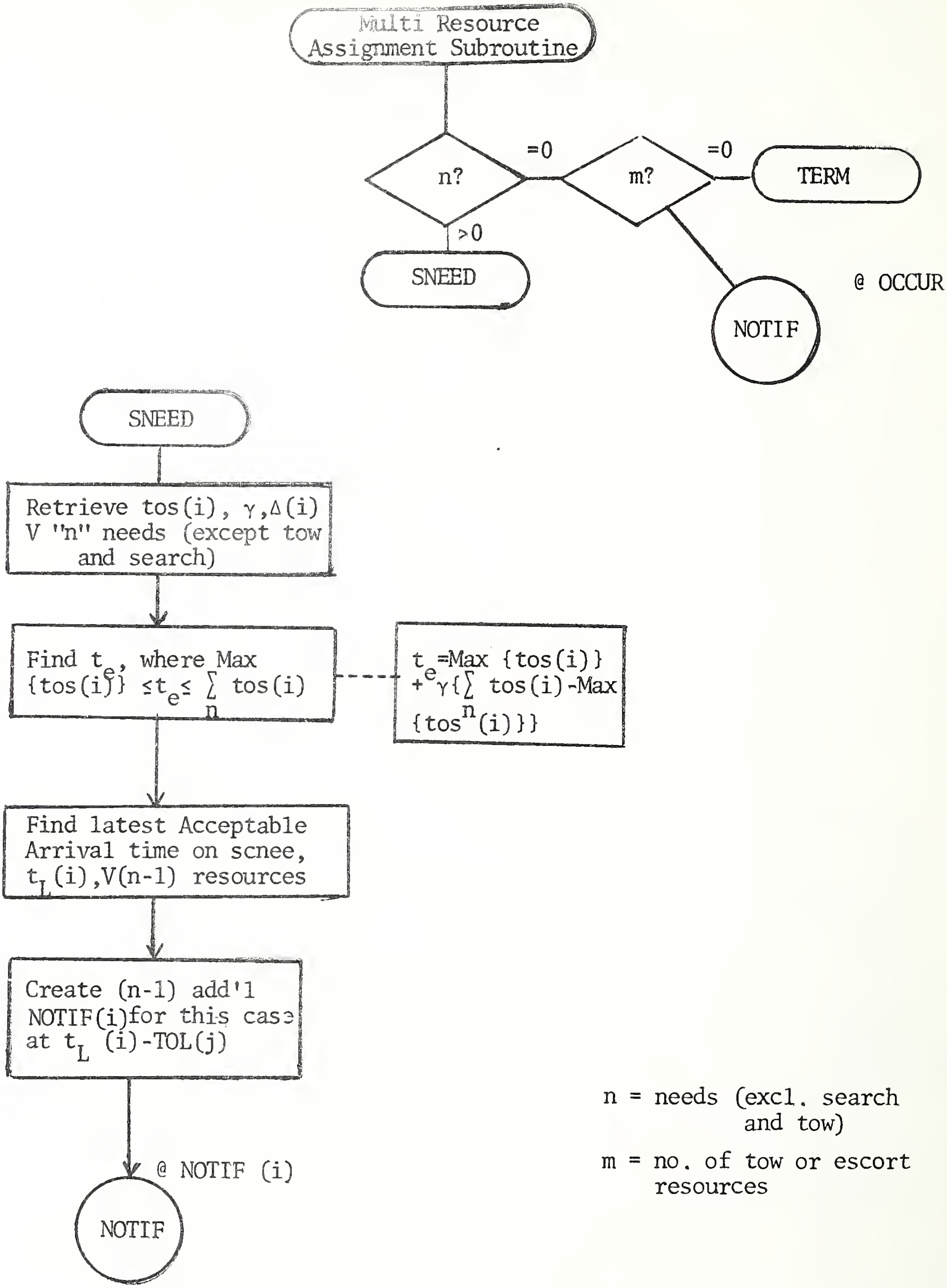
(3) MRAS Logic

When a case requires the service of two or more needs, the OPSIM EXEC passes control to MRAS if the case has no long search requirement. Control is also passed to MRAS from SASS if, at the conclusion of the search, additional service of more than one need is required. Additional notifications of this case are created and an ordered set of capable resources are found at each notification time. Once this set of capable resources has been determined,control is passed to the preselected resource assignment policy (or the redefined policy, based on the user's input relative to the resource selection in SRAS and the desired level of station interaction.) When a resource has been assigned from the set, (SS) is executed to simulate the service of the client's need. Pertinent statistics relative to the client and the resource are also calculated in SS.

Figure 14 shows the flow of operations for the first steps of MRAS, i.e.,scheduling the set of subsequent notification times for the needs of a multi-resource case, excluding search, tow or escort. These notification times are the stimuli to the system for assignment of resources to serve this case's needs. Figure 15 illustrates how a set of capable resources is determined and how the user-controlled switch selects the proper resource assignment policy should certain station autonomy policies be indicated by the user. These steps are elaborated in the ensuing discussion.

(a) Scheduling a Set of Notifications for a Multi-Resource Case

To simulate the dispatch of subsequent resources to service the needs of a case, certain case attributes had to be calculated in



n = needs (excl. search and tow)

m = no. of tow or escort resources

Figure 14
Multi-Resource Assignment Subroutine

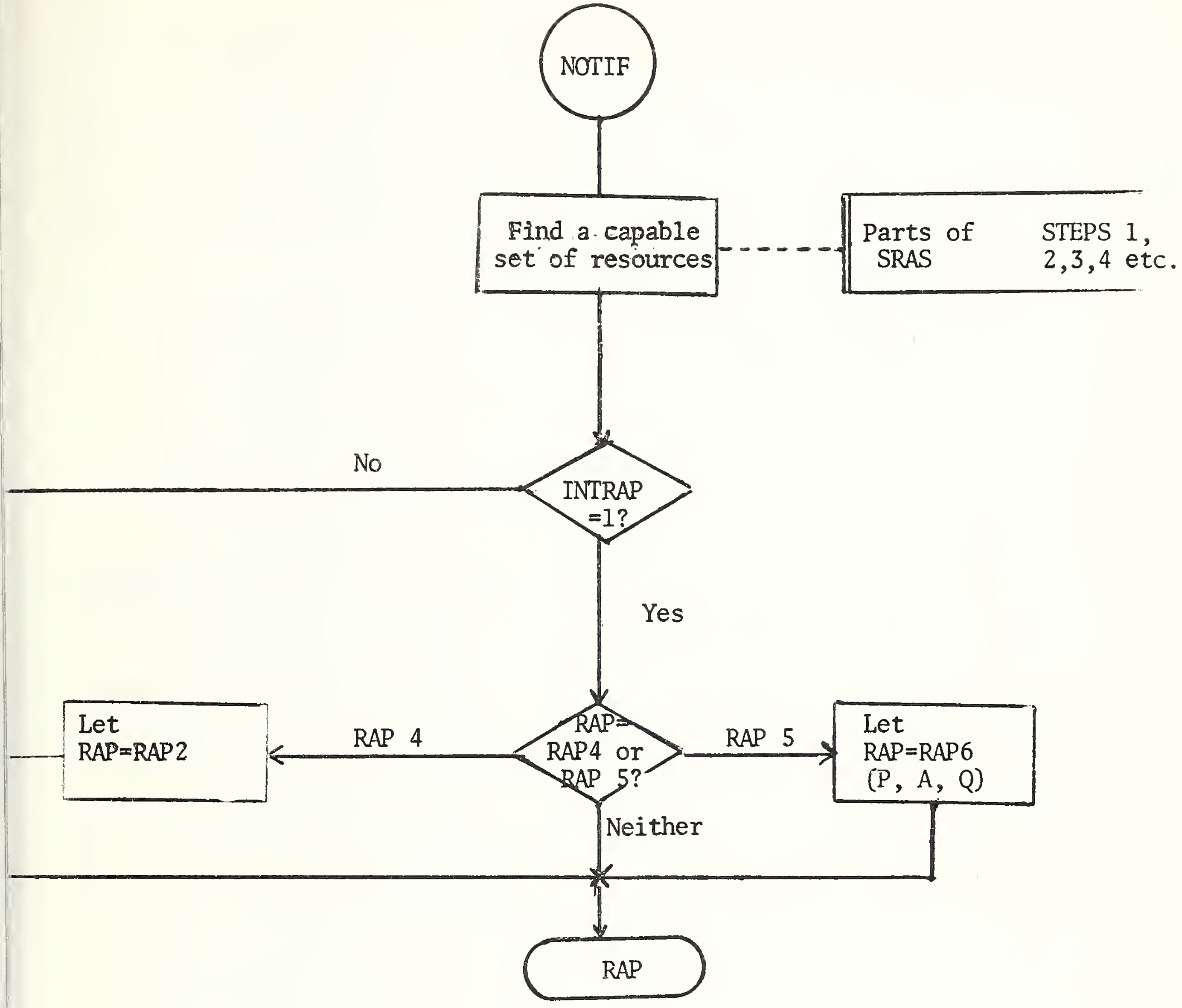


Figure 15
NOTIF

PREPRO relative to the elapsed time of the case and the delay between the arrivals of subsequent resources to the scene of the incident. These attributes include the degree of non-parallel service of the case, γ, and the delay of the commencement of service on scene of the "i" subsequent needs, $\Delta(i)$.

The service of a typical multi-resource case is shown in Figure 16. In this situation, three needs require servicing, but none are search, tow or escort. The first resource is dispatched at t_1 and takes $t_{vec}(1)$ amount of time to traverse to the scene; client is located immediately, and service commences at t_2. The two additional resources arrive on scene at times t_3, and t_4. The resources spend tos(1), tos(2) and tos(3) on scene, respectively. The elapsed time, t_e, that this case is serviced on scene is defined as the time elapsed between t_2 and t_7. When simulating such a case, it is possible that the service of the (three) needs be either in series or in parallel or somewhere between these two extremes.

Referring to figure 17, the range of t_e is given by:

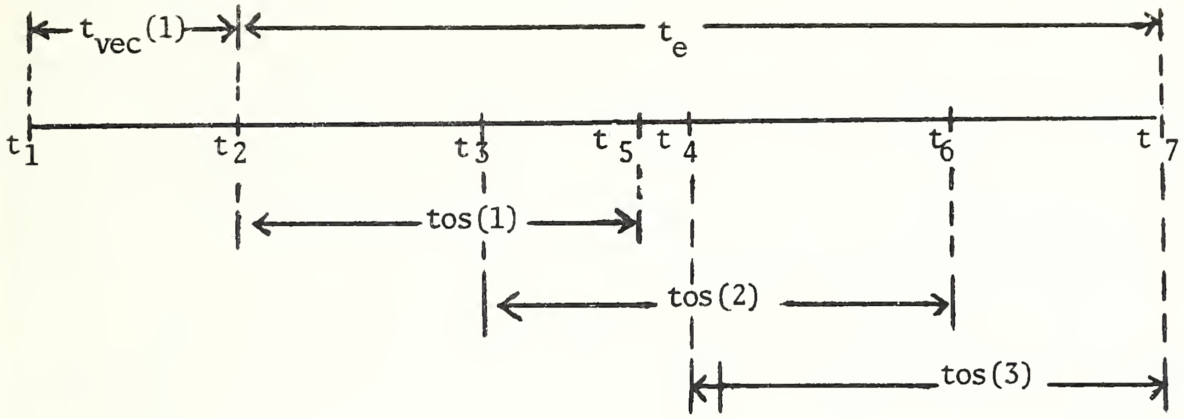
$$\text{Max}\ \{\text{tos}(i)\} \leq t_e \leq \sum_{i}^{n} \text{tos}(i),$$

where the lower bound is strict parallel service and the upper bound is strict series service. The maximum number of needs other than search, tow or escort, is "n". The calculation of t_e is made from the following equation:

$$t_e = \text{Max}\ \{\text{tos}(i)\} + \gamma[\sum_{i}^{n} \text{tos}(i) - \text{Max}\ \{\text{tos}(i)\}]$$

$$\text{where, } 0 \leq \gamma \leq 1;$$

Note that when $\gamma = 0$, the case is served in parallel; conversely, when $\gamma = 1$, the case is served in series. Figure 17 only suggests a



Legend

t_1: System is notified case has occurred. Equivalent to OCCUR.

t_2: First resource arrives on scene.

t_3: Second resource arrives on scene.

t_4: Third resource arrives on scene.

t_5: First resource leaves scene after expending tos(1) amount of time on scene.

t_6: Second resource leaves scene after expending tos(2) amount of time on scene.

t_7: Third resource leaves scene after expending tos(3) amount of time on scene.

$t_{vec}(1)$: Amount of time the first resource spends traversing to the scene.

t_e: The elapsed time the client is provided Coast Guard assistance, on scene, but not including search or tow.

Figure 16
Line Illustration of the Service of a Multi-Resource Case

distribution on γ, of the type which might in the future be used to generate γ by Monte Carlo methods. (This might be appropriate if all other case attributes were obtained via Monte Carlo.) In the current configuration, γ is determined from the case record in PREPRO. (See the PREPRO discussion.)

The parameter $\Delta(i)$ insures that the notification time to the system for need "i" occurs such that the resource could expend its tos(i) within t_e. This $\Delta(i)$ can be viewed as the degree of parallelism among the resources serving a multi-resource case. Its range is given by: $0 \leq \Delta(i) \leq 1$. Conceivably, the elapsed time t_e could later be lengthened should any of the selected resources not be able to arrive on scene within the required tolerance. (See Figure 17 for an illustration of $\Delta(i)$, for the general case.) Subroutine SNEED (see figure 14), using tos (i), γ and $\Delta(i)$, calculates t_e, and the set of notification times {NOTIF(i)} for this case. Each NOTIF(i) is given by:

$$\text{NOTIF}(i) = \text{OCCUR} + \Delta(i)\ [t_e - \text{tos}(i)]\ - \text{TOL}(S)$$

where OCCUR is the notification time of the case. OCCUR will be updated to the time at which the client is found, should MRAS be entered from SASS. (The reader is referred to the discussion in PREPRO on page 59 for the derivation of $\Delta(i)$ from the case record.)

At the notification times, i.e., each member of the set {NOTIF(i)}, control is passed to NOTIF. NOTIF finds a capable resource and selects the proper RAP.

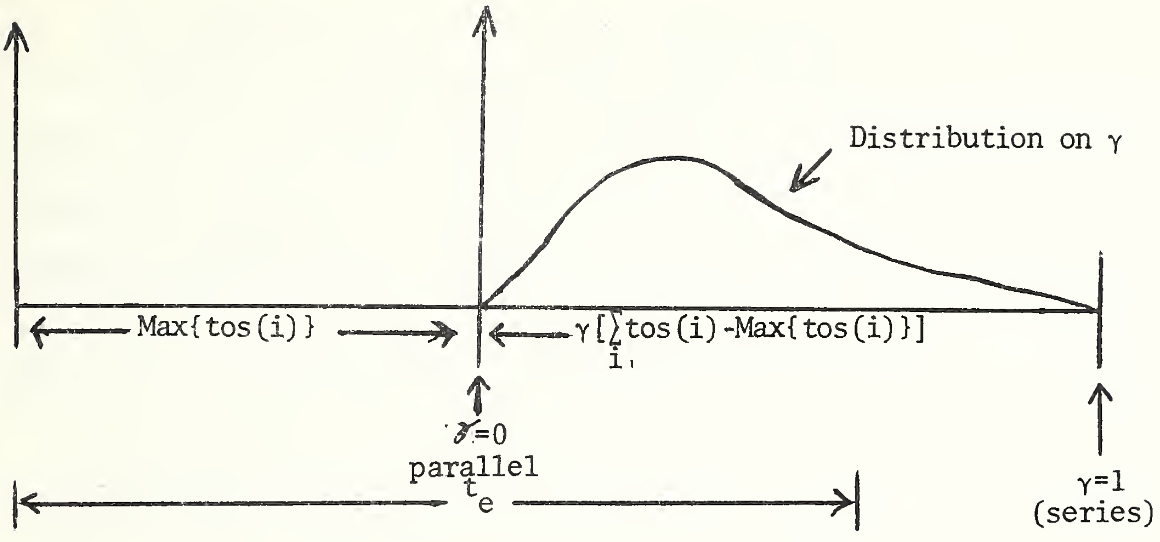


Illustration of a Suggested Distribution on γ

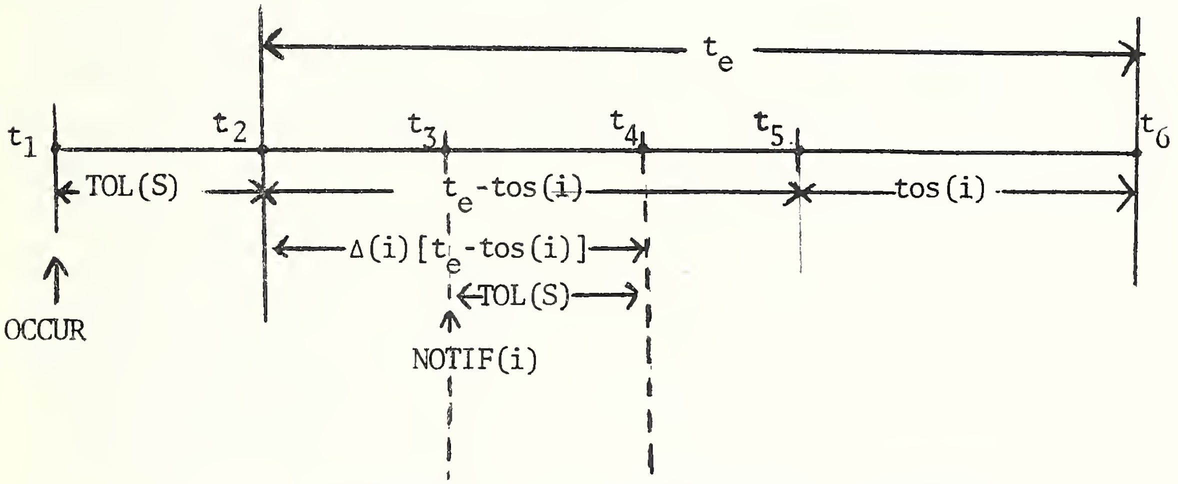


Illustration of Δ(i) General Case: Figure 17

Legend

t_1: Notification of the case arrival to the system, OCCUR.

t_2: Latest possible arrival on scene of first resource within tolerance, TOL(S).

t_3: The system is notified of the requirement of service of the i^{th} need.

t_4: Latest desirable time a resource can arrive on scene to commence service of the i^{th} need, within tolerance TOL(S).

t_5: Latest time a resource can arrive on scene to commence service.

t_6: Service ceases

Figure 17: Illustrations of γ- Destribution and Δ(i)

If the case is a multi-resource tow or escort (a hand-off tow or escort) with no previous needs(other than long duration search),then subroutine NOTIF is called at OCCUR, i.e., when the case arrives to the system or when the client has been found. For the first resource assigned to serve the tow need this procedure is followed. However, the subsequent requests for resources to tow (or escort) are handled in SS, the Service Subroutine. A comprehensive discussion is offered on this subject in the section describing SS* Also, should the case require the service of a single tow or escort after other heeds have been served, this, too, is handled in subroutine SS.

The process for selecting a set of capable resources is the same as in SRAS, (See section 3A(3) of SRAS on page 78 .) That is steps 1, 2, 3 and 4 of SRAS are executed for each need triggered by each NOTIF(i).

Once an ordered set of capable resources has been found, the proper resource assignment policy, RAP, is applied to this set.

(b) Selecting the Correct RAP

The user selected resource assignment policy is input relative to the single resource assignment scheme. For simulation of multi-resource cases, however, an internal switch may be set to allow adjacent stations to participate on multi-resource cases, whereas station autonomy applies to single unit cases.

Referring to Figure 15, with RAP 4 (P, PI, Q) and INTRAP = 1, the computer redefines the RAP for multi-resource cases to be RAP 2 (P, PI, A, AI, Q).Similarly, should the user select RAP 5 (P, Q), then the RAP is redefined as RAP 6 (P, A, Q). If RAP is 1, 2, 3 or 6, then the selected RAP is executed.

---

*See page 123

(c) Interrupting the Service of a Multi-Resource Case

Should a resource serving a need of a multi-resource case,(other than search, tow or escort,)be interrupted,that need of the case is queued. This does not necessarily affect remaining needs. However, the client can neither be towed nor escorted until all the other needs have been serviced. In other words, the macroscopic order of service of the case is preserved; that is, searching for the client must be completed before any need is serviced; and all the needs must be serviced before the client can be towed or escorted.

C. The Search, Assignment and Service Subroutine (SASS) of OPSIM

(1) General Description

The approach to modeling long search cases is quite different from the approach for serving other needs, for which no consideration is given to time spent on scene. (Usually, time on scene varies little from one resource to another when servicing non-search needs.) For search, however, the time required to search a given "area" varies greatly with resource. (Note: search "area" will be carefully defined below.) The primary objective when searching is to select a resource which can cover the greatest fraction of a specified search "area" within a time tolerance or before sunset and, if possible, at least cost.

The duration of a search may be classified as "long" or "short", and is determined in PREPRO. Short searches* are simulated through SRAS or MRAS, and are generally exemplified by resource arrival to service a need other than search, but inability to locate the client immediately. This often derives from erroneous position report or drifting from the

---

*One half-hour or less.

reported position. In contrast, long searches, such as overdues, may last as long as a week or more and may consume considerable resource time. Furthermore, there may be additional needs when the client is located.

It is important to note that the basic use of SARSIM is for planning involving resource allocation and utilization. Consequently, SASS location processes are limited, for the objective is not related to search techniques and tactics. Although future models might perhaps investigate search tactics, more detailed descriptions of cases would be required. The present data base in inadequate to allow estimates of detection probability. For example, neither search width, nor track spacing, nor search pattern, nor search area dimensions are given on the assistance report. Nonetheless, it is possible to extrapolate the number of linear search miles for each participating resource from the hours spent searching. Therefore, the term search "area" is defined in terms of these linear search miles. Given this limited amount of data, the approach of covering an acceptable portion of the required linear search miles in a given tolerance time (or prior to sunset), for a minimum cost is reasonable.

(2) Summary Description of SASS

The typical operational response to a need for search is the assignment of at least one resource, regardless of time of occurrence, if at all possible. This philosophy was incorporated in the modeling effort. Should the case occur after sunset, one resource is sent to the scene, if available. The case is then scheduled for further service, if necessary, and resources are scheduled to arrive on scene at sunrise of the following morning. This procedure is followed in order to provide a timely response. Keeping in mind that nighttime searches are generally relatively ineffective, the bulk of the search effort is scheduled for daylight hours. Should the case occur between sunrise and sunset of a given day, resources are sent to search in order to cover as much of the search "area" as possible before securing for the night at sunset. The search for a client would then continue the following day during the hours between sunrise and sunset until the total number of search miles of the case are exhausted (and the client found, or the search called off).

Endurance limitations, either because of refueling or crew change requirements, of each resource type in the inventory are taken into account in the assignment of the resources to the case, and in scheduling subsequent sorties. This is a user input expressed in hours for each resource type. (See Table .). Refueling is also scheduled when necessary and requires subsequent sorties. The time it takes to refuel is also listed in Table 2.

The PREPRO examines the history of each case in the data base, including hours spent searching, elapsed time of the case, and the search speed of the resource that responded to the case, to develop the equivalent number of resources (operating in parallel) that participated in the search (S_1), and the total linear miles covered in the search (TSM).

Since it is operationally desirable to assign an aircraft/surface resource mix to a search case, the total linear miles are allocated to the resources assigned to the case. This allocation or fractional split

RESOURCE TYPE	FUEL ENDURANCE (HRS.)	TIME REFUEL (HRS.)
UTB(L)	14	0.5
UTB(M)	14	0.5
UTB(U)	5	0.3
MLB(44-52)	14	0.5
MLB 36	14	0.5
MRB/MSB	14	0.5
WPB 95	120	1
WPB	82	1
WYTM/WYTL	120	1
WMEC	UNL+	8
WHEC	UNL+	8
C-130	12*	0.5
HU16E	12*	0.5
HH52A	4.5	0.3
HH3F	6.0	0.3

+999 Hours

*Assumes Double Crew

TABLE

Fuel Endurance and Refuel Time (Hrs.)

is a user input, the only requirement being that the fractions must add to unity. To demonstrate this concept, consider a case requiring two search resources. The user input for the split between two search resources could be, for example, 0.70 and 0.30. Using the assignment criteria, most likely an aircraft would be assigned to cover 0.70 of the total miles while a surface resource has a good probability of being assigned the remainder, 0.30. Recall that the assignment criterion is based on the least expensive resource that will cover an acceptable fraction of the desired amount of search "area" within tolerance or before sunset.

One additional user input helps to control the intensity and duration of the search by allowing the user to place emphasis on any desired day of the search. (For example, the user may choose to emphasize the first day.) This input variable is PDC(DAY). It may be desirable to attempt to cover, for example, at least 50% of the search miles on the first day and at least 20% of the remaining search miles on subsequent days. This example models an initial concerted search effort followed by a decreased emphasis on subsequent days.

(3) Inputs to Operate SASS

(a) The additional case attributes, other than those discussed in SRAS but required by SASS,include the following: (These attributes are developed in PREPRO).

(i) TSM: Total (linear)search miles on the case.

(ii) S_1: Total number of search resources required on the case.

(iii) n: The number of needs except search, tow or escort.

(iv) m: The number of sequential tows or escorts required

(v) P: Primary station of the case.

(vi): S: Severity level of the case.

(vii) $\left.\begin{matrix}XC\\YC\end{matrix}\right\}$ Case location.

(b) The additional user inputs include:

(i) SUNSET and SUNRISE times (Seasonal variations can be introduced by exercising either a peak or non-peak scenario.)

(ii) (TOLS(S): Tolerance times for searching as a function of severity level, S, of the case.

(iii) $SOA_3(L)$: Search speed of the Lth type resource.

(iv) END(L): Endurance (hours) of Lth type resource.

(v) $t_f(L)$: Time it takes the Lth resource to refuel.

(vi) OC(L): Operating cost/hour for the Lth type resource.

(vii) PDC(DAY): Desired percentage of the search miles to be covered by each search resource as a function of the DAY of the search.

(viii) PRTSM(i): Fractional split of TSM among the S_1, search resources assigned to the case, (i=1, 2, ..., S_1).

(ix) x: The number of hours before SUNRISE when an attempt is made to assign resources to search cases secured the night before.

(x) INTRAP: INTernal (adjacent inclusive) Resource Assignment Policy switch.

(4) SASS Logic

SASS is called by the OPSIM EXEC if S_1, the number of resources on a long search case, is at least one. Any other subsequent need requirements are later served through SRAS and MRAS, depending on the values of n and m.

The first step in SASS is to allocate to each resource that portion of the total search miles, TSM, indicated by the values of PRTSM(i). (See Figure 18.) The result is a set{SM(i)} of search miles allotted to each resource. Table 3 below illustrates how the user may define the fractional split of these miles as a function of the value of S_1, the number of search resources. The set {SM(i)} is given by:

$$SM(i) = TSM * PRTSM(i), \text{ where } i = 1(1)\ S_1.$$

OCCUR, the time the case enters the system, is examined next. Should the case take place during the hours between SUNRISE minus x hours and SUNSET of a given day, SASS1 is called after notifications have been created for each SM(i). Creating additional notifications to the system treats the case as a set of single resource cases, each having a requirement for covering SM(i) search miles. Should the case enter the system sometime after SUNSET, but prior to SUNRISE minus x hours, then a single resource, if available, is vectored to the scene immediately. The remaining S_1-1 required SM(i)'s are placed in a SUNRISE LIST, via RISE, to be served at SUNRISE minus x hours. In order to model the concerted effort approach to cases occurring at night, the values PRTSM(i) should be input in descending order of magnitude.

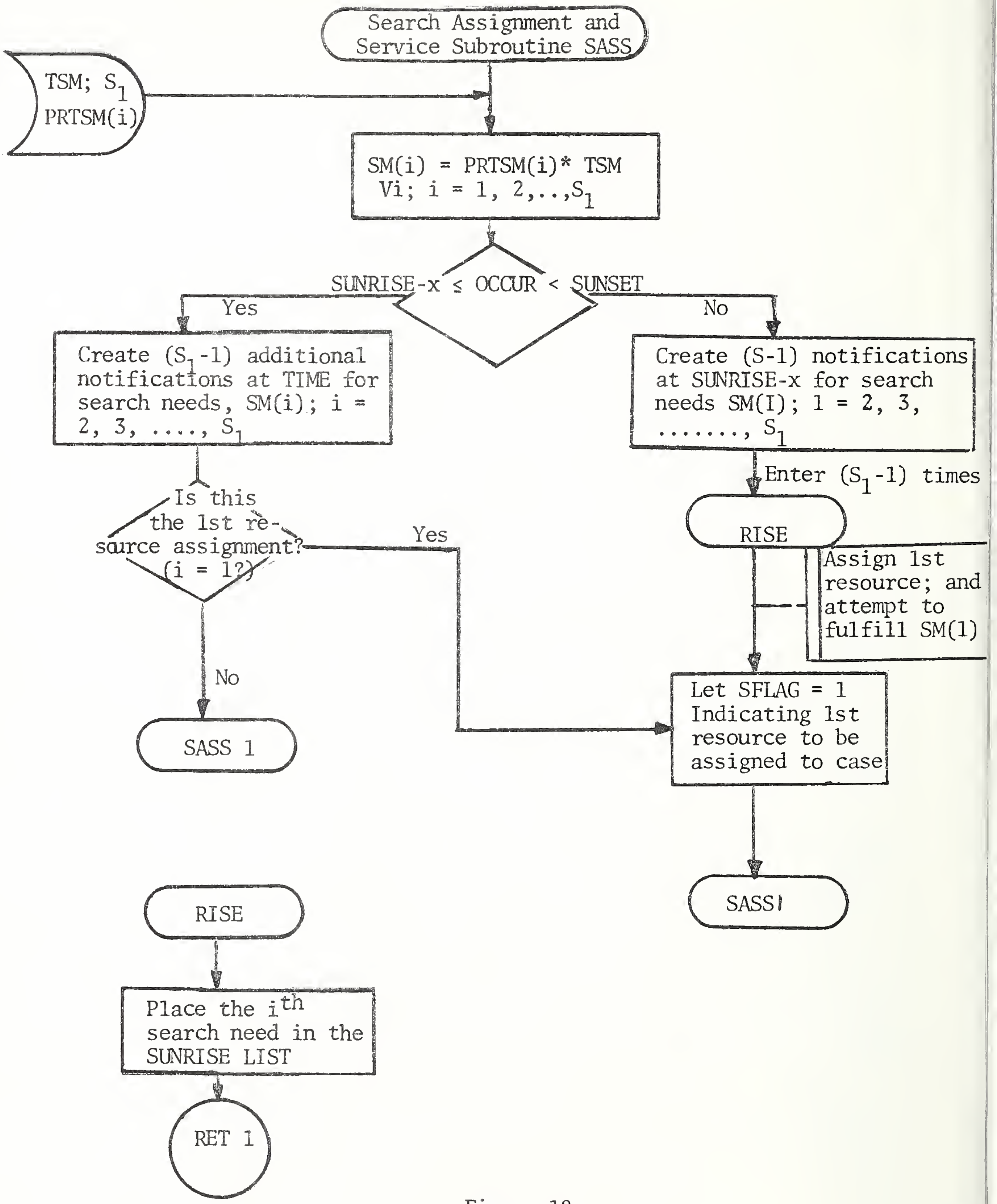


Figure 18
SASS Flowchart; RISE

PRTSM(i)

S_1 i	1	2	3	4	5
1	1.00	-	-	-	-
2	.70	.30	-	-	-
3	.50	.30	.20	-	-
4	.30	.30	.20	.20	-
5	.30	.25	.20	.15	.10

Table 3

Fractions of PRTSM(i) for varying levels of S_1.

SASS1 finds an ordered set of capable resources at the primary and adjacent stations and uses setps 1 and 2 of SRAS. (See Figure 19.) An attempt is made to complete the search miles, SM(i),within search tolerance time, TOLS(S), or before SUNSET for long search cases. Comparing the current simulation clock time, TIME, plus TOLS(S) to SUNSET defines the amount of time available to search before securing for the night at SUNSET. This applies to aircraft only, as surface resources are permitted to search at night to their endurance limits. Each resource type has some capability to search; whether they are all capable to serve this particular case depends on the environmental conditions. The appropriateness of selecting a resource is also a function of each one's ability to cover an "area" satisfactorily. For each of the K capable resources, PR(k) is calculated to represent the percentage of the "area" which that resource can cover within TOLS(S), or before sunset. This is a function of the position of each resource relative to the case, the vector and search speeds of each resource

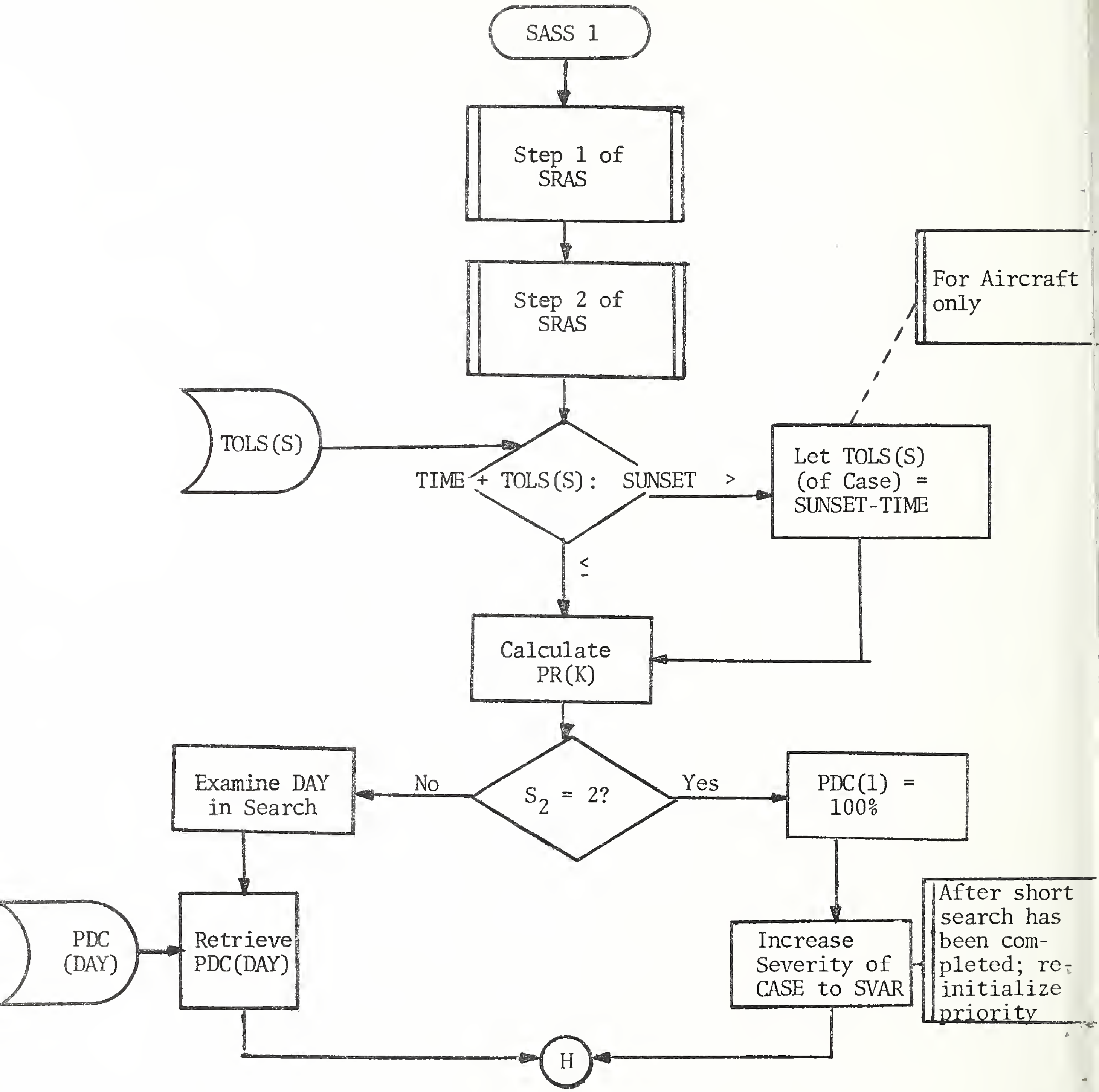


Figure 19
SASS1 Flowchart

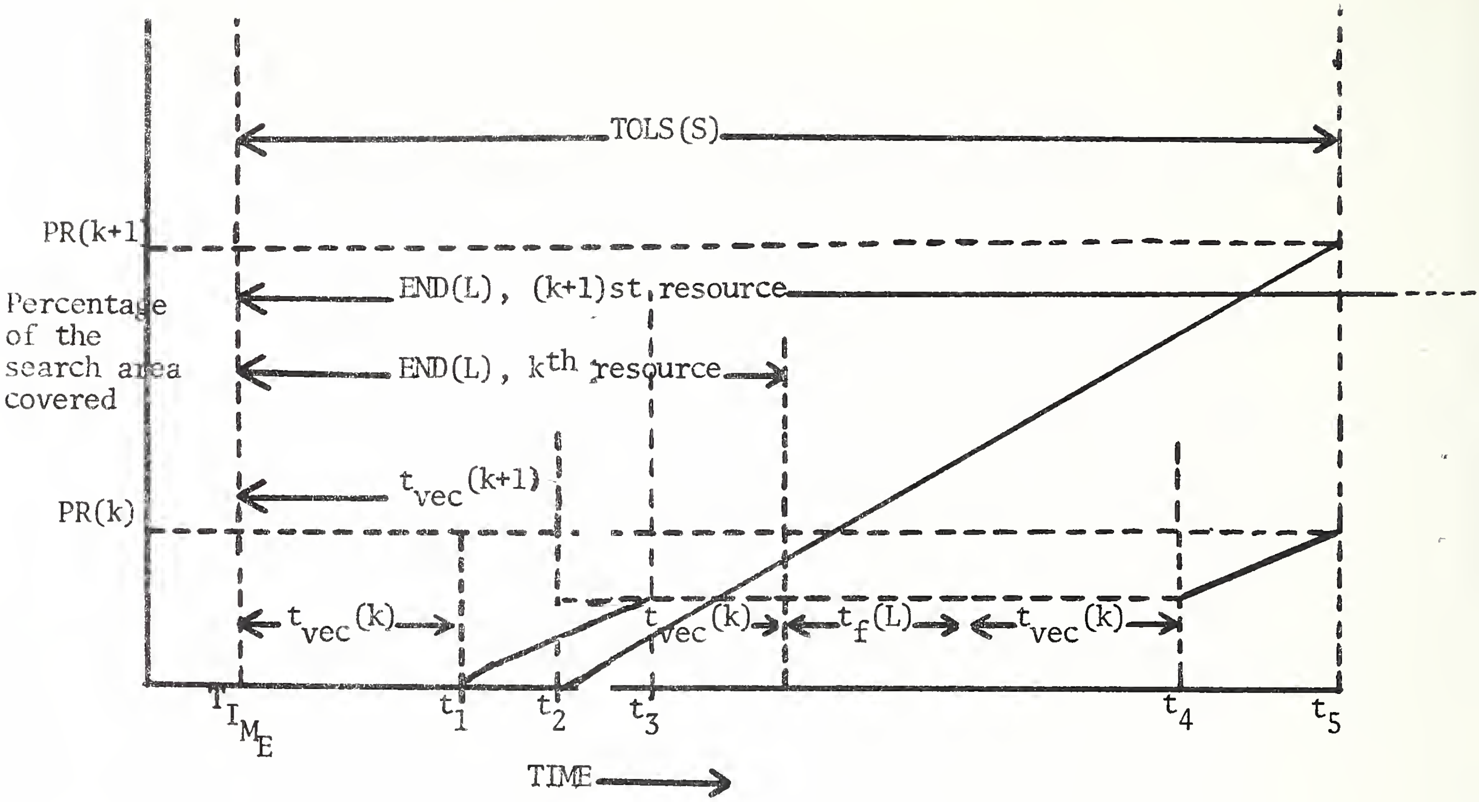
and the endurance and refuel times of each capable resource. The calculation of PR(k) is best illustrated by referring to Figure 20.

Consider two capable resources, the kth and (k+1), which can start for the search area at some simulation clock time, TIME. The kth resource which has a shorter endurance than the (k+1)st, arrives at the search area at time t_1 after expending $t_{vec}(k)$ to arrive on scene.* It must depart the area at t_3 to return home and spend $t_f(L)$ amount of time refueling, then takes $t_{vec}(k)$ amount of time to return to the search area, arriving at t_4 to continue searching. The slope of the straight lines between t_1 and t_3, and between t_4 and t_5, $SOA_3(L)/SM(i)$, is the normalized rate of coverage for this resource, where $SOA_3(L)$ is the search speed. PR(k) is the product of this rate and the accumulated time spent searching. The (k+1)st resource arrives on scene at t_2 and searches until t_5, covering PR(k+1). Both resources stop searching at TIME + TOLS(S).

Once the set of PR(k)'s is calculated, the desired coverage level, is retrieved. For those short search cases which require an additional resource to search(i.e., $S_2 = 2$),SASS1 is called with PDC(DAY) = 100%, and DAY equal one (since it is desirable to cover the entire search area that first day before serving any additional need on these short search cases). Also, the severity of the case may be increased (as specified by the user) in this case to the

---

*It is assumed here that in the typical operational situation the searching resource is dispatched from its home station, rather than from whatever location happens to obtain at that moment. Little accuracy is lost in the calculation of PR(k) as a result of this assumption.



For any capable resource R, the percentage area covered, PR(R), is given by the following equation:

$$PR(R) = \frac{SOA3(L)}{SM(i)} \left\{ \{END(L) - 2t_{vec}(k)\} \left[\frac{TOL(S)}{END(L) + t_f(L)}\right] + TOLS(S) - \{END(L) + t_f(L) \left[\frac{TOL(S)}{END(L) + t_f(L)}\right] - t_{vec}(k) \right\},$$

(Note: Figure 20 is continued on the following page) where, $\left[\frac{TOLS(S)}{END(L)+tf(L)} \right]$ represents the largest number possible integral of sorties (during TOLS(S) the resource expends a maximum amount of time, subject to its endurance limitations); and, the following conditions hold:

A. $\{END(L) - 2\ t_{vec}(k)\} > 0$

B. $TOLS(S) - \{END(L) + t_f(L)\} \left[\frac{TOLS(S)}{END(L)+t_f(L)} \right] - t_{vec}(k) \geq 0$

C. $\{END(L) - 2t_{vec}(k)\} \geq TOLS(S)-\{END(L)+t_f(L)\} \left[\frac{TOLS(S)}{END(L)+t_f(L)} \right] - t_{vec}(k)$

D. $PR(k) \geq 0$

In addition, certain situations can occur, and PR(k) takes on other forms. These are:

A. If $\{END(L) - 2\ t_{vec}(k)\} \leq 0$, then $PR(k) = 0$

B. If $TOLS(S) - \{END(L) + t_f(L)\} \left[\frac{TOLS(S)}{END(L) + t_k(L)} \right] - t_{vec}(k) < 0$,

then $PR(R) = \frac{SOA3(L)}{SM(i)} \left\{ \{END(L) - 2t_{vec}(R)\} \left[\frac{TOLS(S)}{END(L)+t_f(L)} \right] \right\}$

C. If, $TOLS(S) - \{END(L) + t_f(L)\} \left[\frac{TOLS(S)}{END(L)\ +t_f(L)} \right] - t_{vec}(R) > \{END(L) - 2\ t_{vec}(k)\}$

then $TOLS(S) - \{END(L) + t_f(L)\} \left[\frac{TOLS(S)}{END(L)+t_f(L)} \right] - t_{vec}(k) = \{END(L) - 2t_{vec}(k)\}$

and $PR(k) = \frac{SOA3(L)}{SM(i)} (END(L) - 2t_{vec}(k) \left\{ \frac{TOLS(S)}{END(L)+t_f(L)} + 1 \right\}$

Figure 20 (continued)

value SVAR to ensure quick response and non-interruptibility of this additional resource. The cost, C(k), for each capable resource is calculated using the following equation:

$$C(k) = OC(L)*(t_{vec}(k) + SM(i)/SOA_3(L))$$

Cost as calculated here includes the total time spent searching and the cost to vector to the scene.

Those resources whose PR(k) meet the desired PDC(DAY) are ranked on increasing cost. Those resources whose PR(k) is less than the desired, are ranked on decreasing PR(k). Finally, those resources which cannot cover any area before TOLS(S), but can at least vector to the search area and return within endurance, are ranked in increasing $t_{vec}(k)$. The cost for any additional sorties required because of limited endurance is not directly calculated here, because these resources are already penalized in the PR(k) calculations.

A final merged list is created listing ranked capable resources first by increasing cost, next by decreasing PR(k), and last by increasing $t_{vec}(k)$. (See Figure 21.) Control is passed to RAP to find a resource at the primary (and adjacent) stations(s) to service the case from this list. (The internal switch INTRAP is activated as in MRAS should the selected resource assignment policy be RAP 4 or RAP 5.)

SSS, the Search Service Subroutine is called once the capable resource is found in RAP. Within SSS, if this is the first resource assigned to the case,(i.e.,SFLAG is unity),control is passed to TEST. The objective is to vector the first resource immediately to the scene

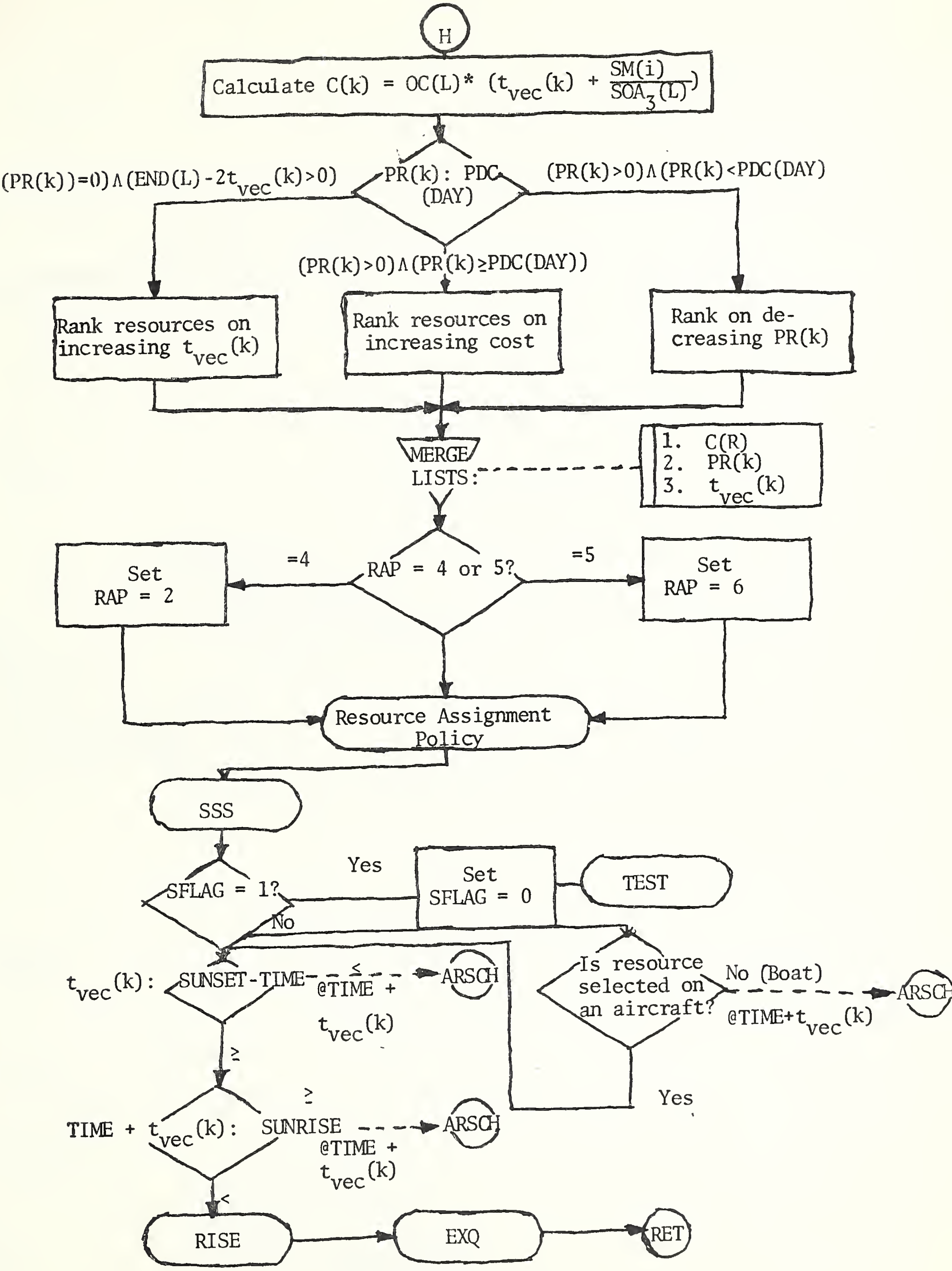


Figure 21
SASS and SASS1 Cont'd

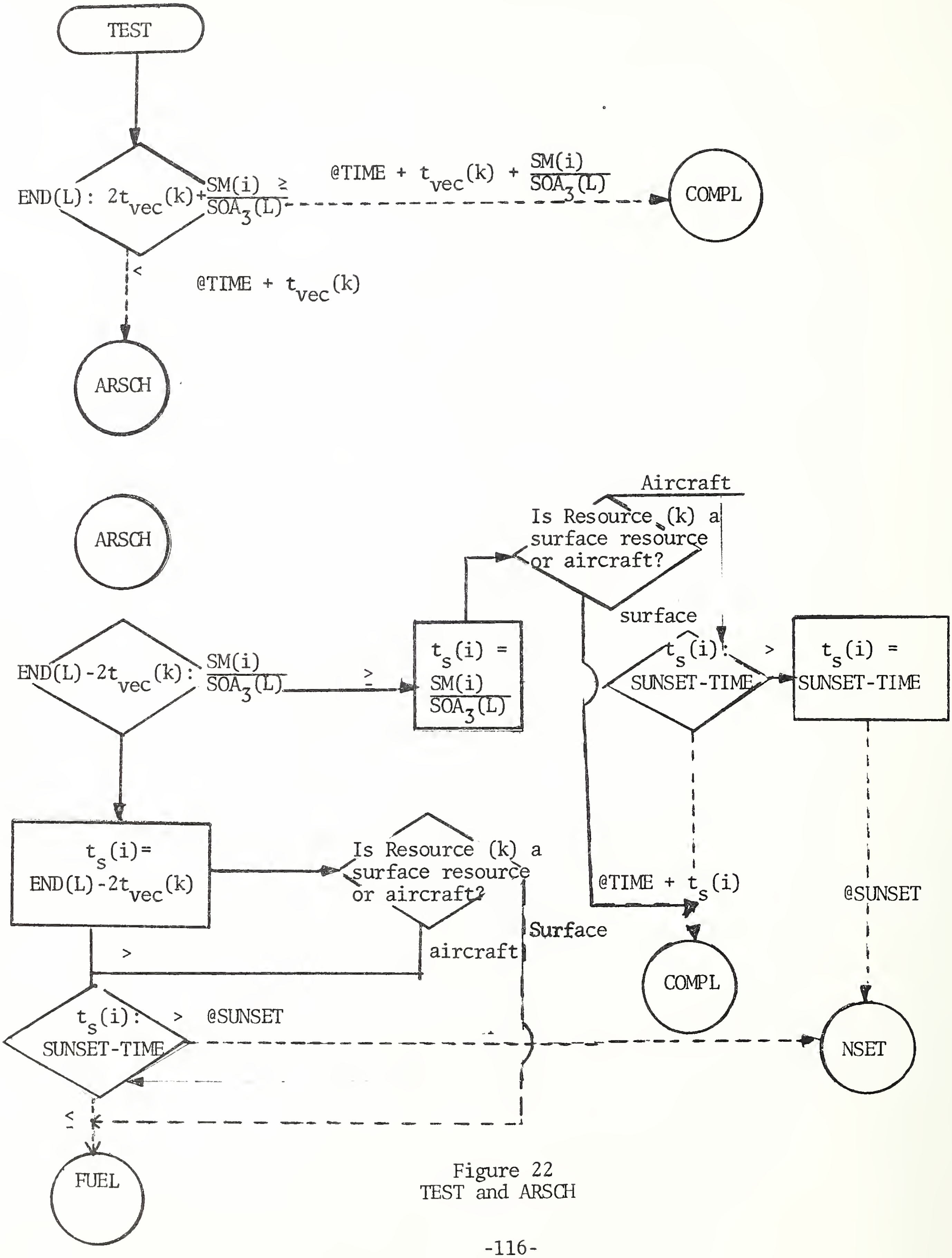


Figure 22
TEST and ARSCH

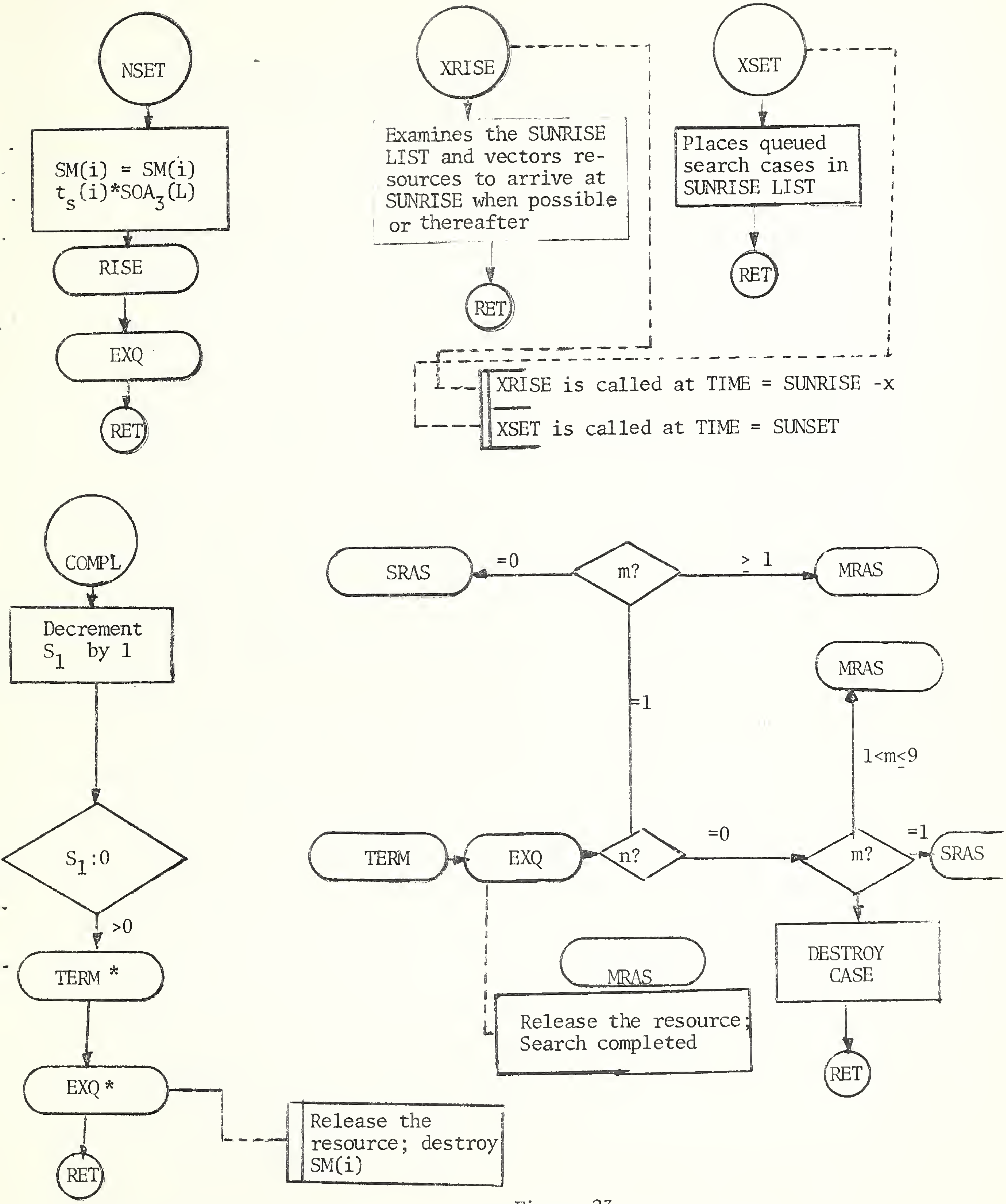


Figure 23
NSET; XRISE; XSET; and COMPL

---

*See SS routine

to commence searching for the client. (See Figures 21 and 22.) TEST compares the endurance, END(L), against the total time required on the case, (i.e., to vector to and from the scene, $2\ t_{vec}(k)$; plus the time to search, $\frac{SM(i)}{SOA_3(L)}$). If END(L) compares favorably, then the resource is sent to the scene and control is passed to event routine COMPL at the end of service of the case. It is assumed that the longer endurance resources will remain on scene searching during the night. COMPL (see Figure 23) passes control to TERM and subsequently to EXQ. TERM terminates the search need of the case just served, while EXQ examines the queue for a case or a need of a case that can be serviced by the resource which just became idle (i.e., completed serving the search need). (See the following section on SS for discussions of TERM and EXQ.) COMPL also examines the case to determine if any subsequent needs beyond search require service. Control is passed to SRAS or MRAS dependent on the values of n and m.

If, on the other hand, the first selected resource's endurance is less than the total expected time required to spend searching, then control is passed to ARSCH, at the time the resource arrives on scene to commence search. (See Figure 22.)

The subroutine ARSCH schedules the completion of the search need or additional sorties (if refueling is required to complete the service of the case); updates the SM(i) to be covered; and secures the case for the night, if necessary. To model the search capability of certain resources more realistically, aircraft are prevented from continuing their searching after sunset, whereas surface resources are permitted to continue to search beyond sunset, but within their endurance constraints.

If the selected resource is an aircraft and the required search time, $t_2(i)$, can be expended within endurance and vector time limitations and prior to SUNSET, then COMPL is called at the end of the search time. If instead, SUNSET occurs before the aircraft can fulfill its $t_s(i)$, the search is secured for the night, and the $t_s(i)$ is updated to the amount of time remaining until SUNSET. Since this search need has not been fulfilled, control is passed to NSET at SUNSET. NSET updates the remaining search miles SM(i), places the need in the SUNRISE LIST via subroutine RISE, and calls EXQ. The SUNRISE LIST is examined at SUNRISE-X hours. Surface resources remain on scene covering their assigned SM(i) if the endurance limitations have not been exceeded. Upon completion of $t_s(i)$ COMPL is called.

In the instance where the selected resource cannot cover its assigned SM(i) within endurance, sorties are scheduled to complete the search need. The resource can only search that amount of time representing the difference between the endurance and the time to vector to and from the scene. This time becomes $t_s(i)$ in this instance. Surface resources remain on scene (beyond SUNSET if necessary) expending their assigned $t_s(i)$, returning home to refuel. Aircraft will remain on scene and search until SUNSET or until they have spent their $t_s(i)$, whichever occurs first. In the latter case, if SUNSET occurs first, then NSET is called. If refueling is required to continue service of this case, prior to SUNSET, then control is passed to FUEL.

The number of search miles SM(i) are updated in FUEL and control is passed to HOMEF, where the resource is refueled. The resource becomes available to be vectored back to the search "area" after expending $t_f(L)$ time refueling. HOMEF passes control to SNDBK. Subroutine SNDBK first attempts to find a "better" idle capable resource to fulfill the remaining search requirement. This is done with a call to SASS1. If no resource can be found, then the original resource is assigned to continue searching.

In Subroutine SNDBK,a resource will be vectored back to the search area if he can arrive prior to SUNSET of that day, or if his vector time is so large that the resource will arrive on scene after SUNRISE minus X hours of the next day. Should the resource not be able to arrive before SUNSET, but can arrive at SUNRISE minus X hours or after, then the search need is placed in the SUNRISE LIST via RISE. (See Figure 24 illustrations of FUEL, HOMEF, and SNDBK.)

The discussion relative to SSS thus far has covered the first resource assigned to a case, and the scheduling of subsequent sorties for any resource selected to serve a search need of the case. Referring back to Figure 21, if this resource is not the first one on the case but is a surface resource, then control is passed to ARSCH when the resource arrives at the search area. If,however, the resource is an aircraft, then it is vectored to the case if it can arrive on scene prior to SUNSET or if the vector time, $t_{vec}(k)$, is so long that the resource will not arrive until after SUNRISE of the next day. Should the aircraft not be able to arrive before SUNSET, but can arrive prior to SUNRISE of the next day, the case is placed in the SUNRISE LIST via RISE, and EXQ is called.

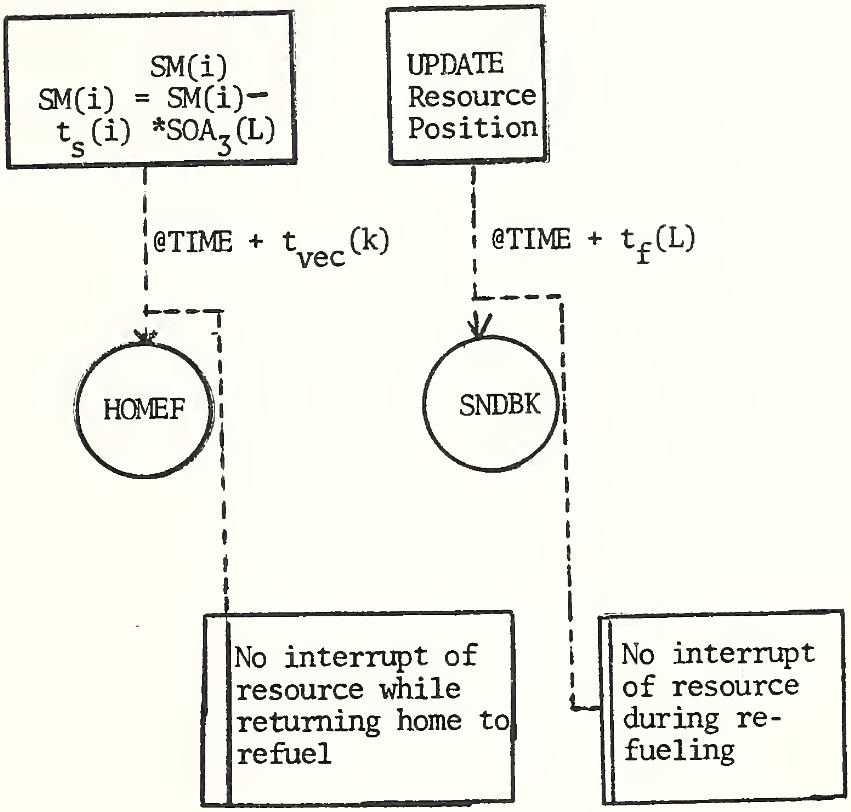


Figure 24

TEST; ARSCH; FUEL; HOMEF; and SNDBK

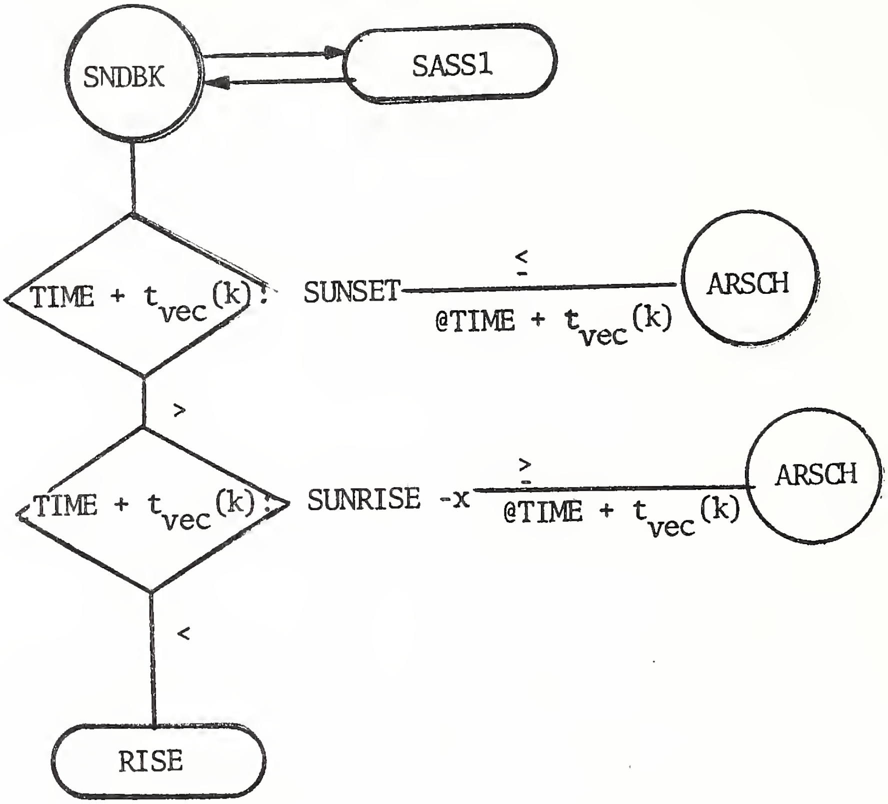


Figure 24 (continued)

The event XSET is called automatically at SUNSET. It has been created to specially handle queued search cases. XSET extracts search cases from the queue and places them in the SUNRISE LIST.

XRISE examines the SUNRISE LIST at SUNRISE minus X hours and vectors resources at appropriate times to arrive on scene at SUNRISE. These routines are illustrated in Figure 23.

D. The Service Subroutine (SS) for SRAS and MRAS of OPSIM

(1) General Description

Once a resource has been selected to service a need in either SRAS or MRAS, control is passed to the Service Subroutine, SS. This routine simulates the required service activities; the continuous coverage of the client, should it be required in a multi-resource case; the re-evaluation of the severity level of the case during the elapsed service time, etc.

Upon completion of the service of a need of a case, the resource assumes an idle (alpha) status. The case statistics relative to servicing this need and the statistics regarding the utilization of the resource are recorded. The queue is examined for waiting cases at the resource's primary and adjacent stations, depending on the selected resource assignment policy, to determine if the released resource is capable of serving a waiting case before returning to home port.

(2) Inputs

The operation of SS is dependent on the case attributes and the user inputs. Certain simulation-developed case attributes are, of course, carried for statistical analysis purposes.

(a) Case Attributes

The Case attributes used in SS include:

(i) tos(i): The time on scene for the i^{th} need.

(ii) n: The number of needs other than search or tow.

(iii) m: The number of tow or escort resources.

(iv) S_2: The indicator for a short search requirement.

(v) TSM: The miles to be covered searching for the client (also required for a short search).

(vi) S: Severity level of the case.

(vii) NEED: Explicit need of a case undergoing service.

These attributes were discussed in the section on PREPRO.

(b) User Inputs

The user inputs are a combination of operational experience and extrapolation of historical data:

(i) DRS(j): Probability distribution for re-evaluation of the case severity level, i.e., the severity level becomes S + IPC, where DRS(1): % Increase by a unit, IPC = 01; and DRS(3): % No change, IPC = 0.

(ii) KS: The number of examinations, on scene, of the case severity.

(iii) HU: Distribution for hook-up time tor tow cases (or delay for surface escort cases).

(The time required to obtain the information required in the SAR assistance form is not specifically included in the service time, nor is there an allowance for any delay for "unhook" time. In most instances these activities require a relatively minor fraction fraction of the total service time of the case.)

(iv) HO: Hand-off point, (miles from shore) for multi-resource tows, or escorts.

(3) SS Logic

Control is passed to SS after the assignment of a resource (to serve the i^{th} need of a case) is made in RAP. ARVSN is called at the time the assigned resource arrives on scene or at the expected location of the client.

ARVSN performs a number of functions which include: passing control to SRCHF, a subroutine which simulates the activities for locating the client under short search conditions; calling ONSCN, a subroutine which simulates the re-evaluation of the cases severity level as time passes during the servicing of a need; and releasing a resource which serviced a previous need and had covered the client until another resource could arrive on scene. RETN is called when coverage is no longer required. (See Figures 25-27.)

If the case is a multi-resource case, coverage is provided for the client unless the covering resource is interrupted to serve a higher priority case. Therefore, upon arrival on scene, should a resource be on scene and waiting, after having served a need of this case, the waiting resource is released. This is done in RETN. (See Figure 27.) TERM and EXQ, called by RETN, record statistics on the case and resource, and examine the queue to serve waiting cases, respectively. These routines are explained later in the discussion.

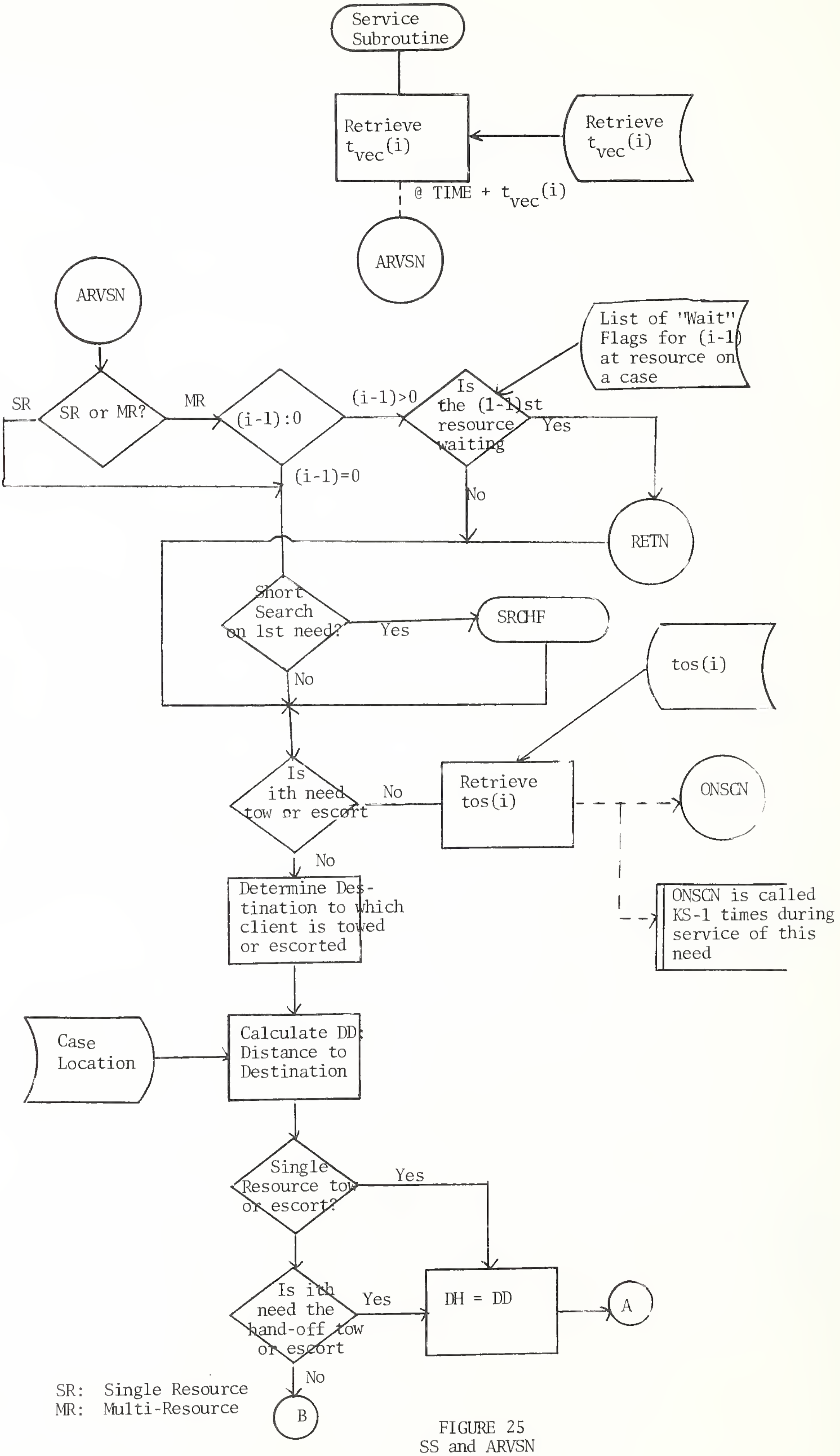


FIGURE 25
SS and ARVSN

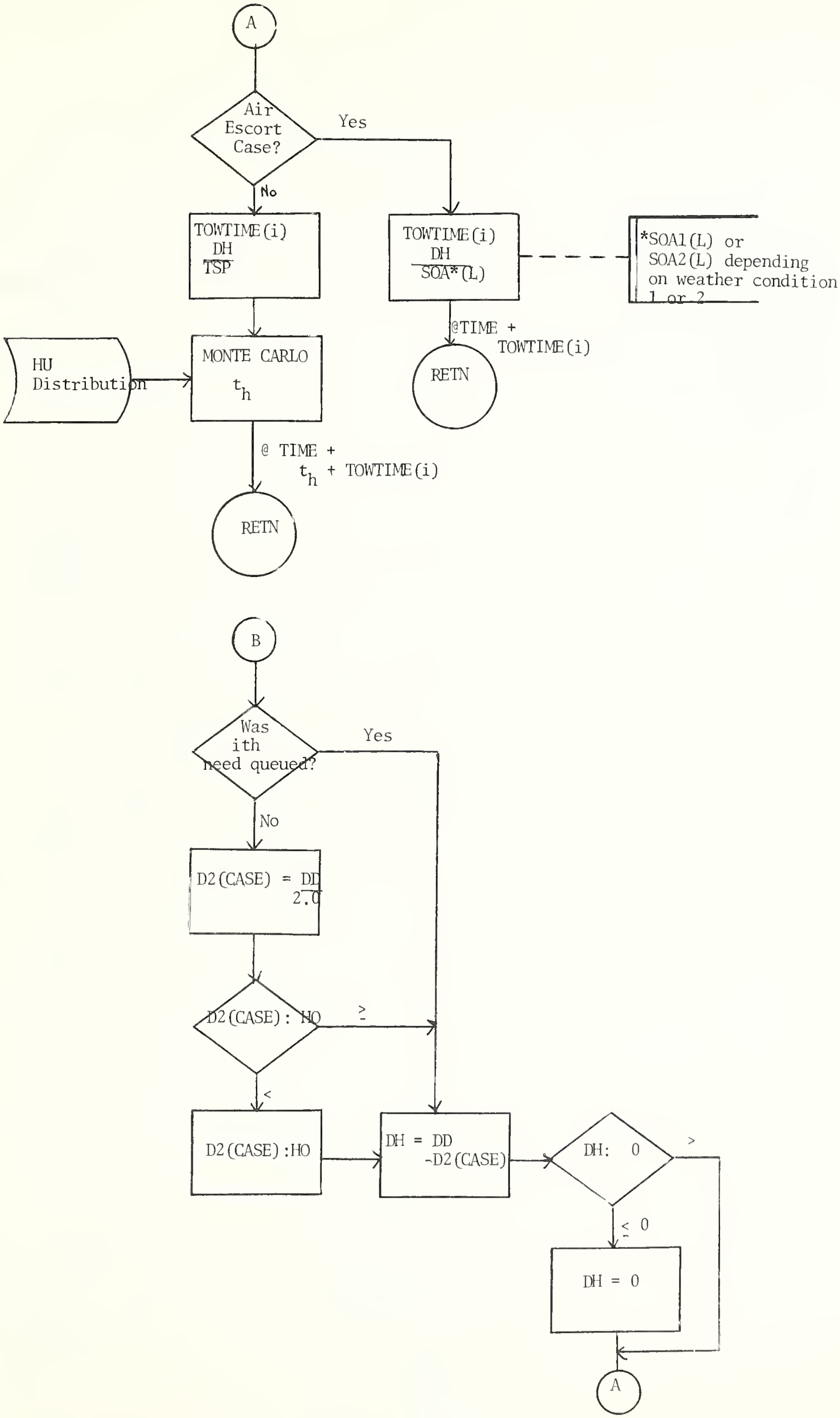


Figure 26
ARVSN (continued)

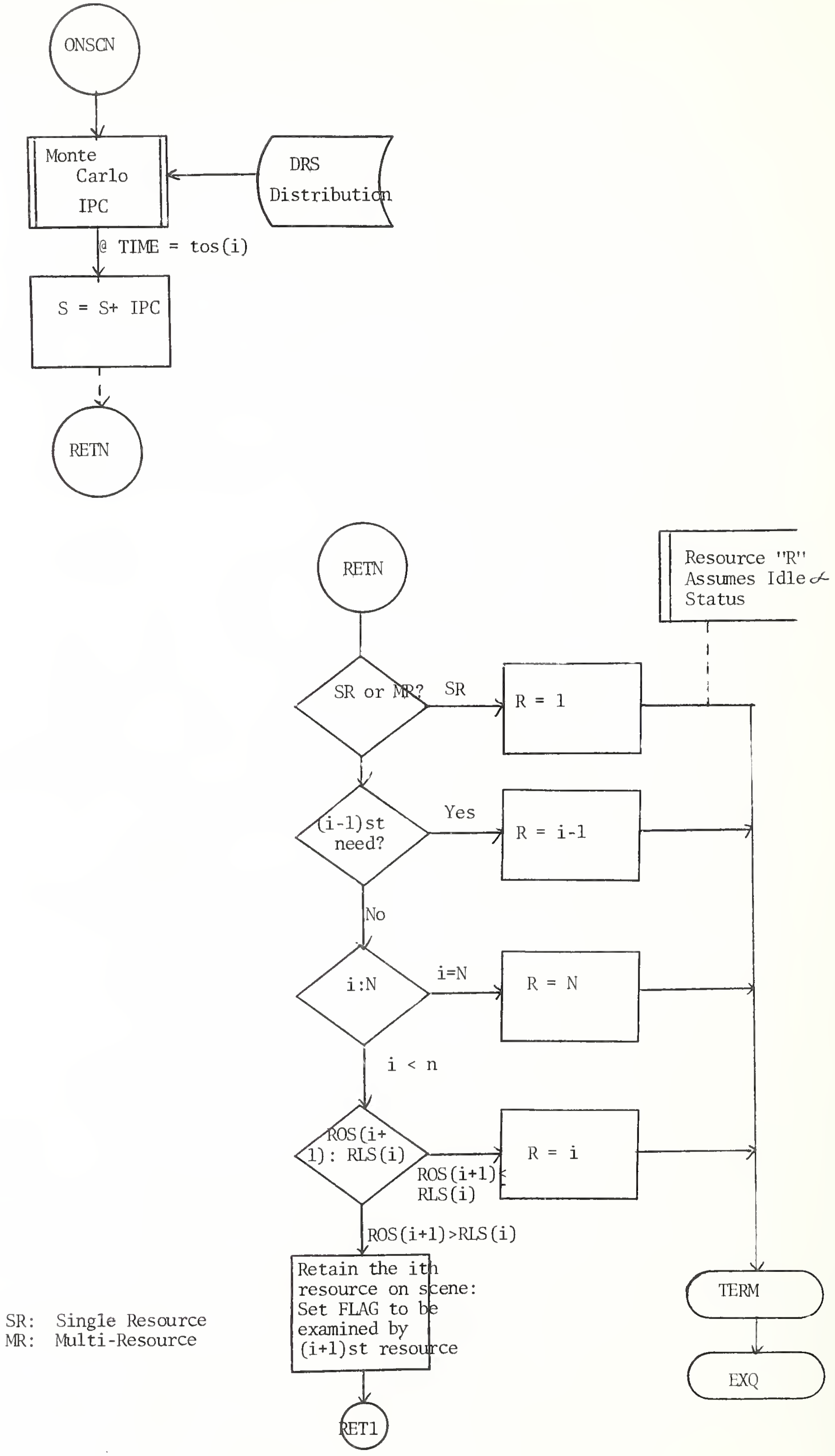


Figure 27
ONSCN and RETN

SRCHF is called if a short search is required only on the service of the first need. An attempt is made here to simulate the typical situation where a resource has been vectored to the expected location, but cannot find the client. The position may have been erroneously reported, or the client may have drifted from his last reported position. The resource must search for the client or call up an additional resource to perform the search. (See Figure 28.)

Before a client can be towed (or escorted), his destination must be established. Ordinarily the client's destination is the primary station (i.e., the case's primary station). However, in the situation where the client is being towed (or escorted) by a resource on patrol, then the client is towed to a predesignated station for that patrol resource. (Each patrol resource's predesignated station is treated as an adjacent to the patrol station, where the patrol station is considered a primary. Each patrol station will have on adjacent.) Once the destination is known, the distance to that point, DD, is calculated.

Analysis of the historical data indicated that very few tow or escort cases required more than a single hand-off, implying that, in most cases, not more than two resources towed, or escorted, in series. The decision was therefore made to limit the maximum number of hand-offs to one, or the case will have a maximum of two tow needs (or two escort needs). (Cases involving more than one resource to tow or escort will automatically be reduced to two resources.) The request for tow or escort is made at the arrival of the case to the system, or

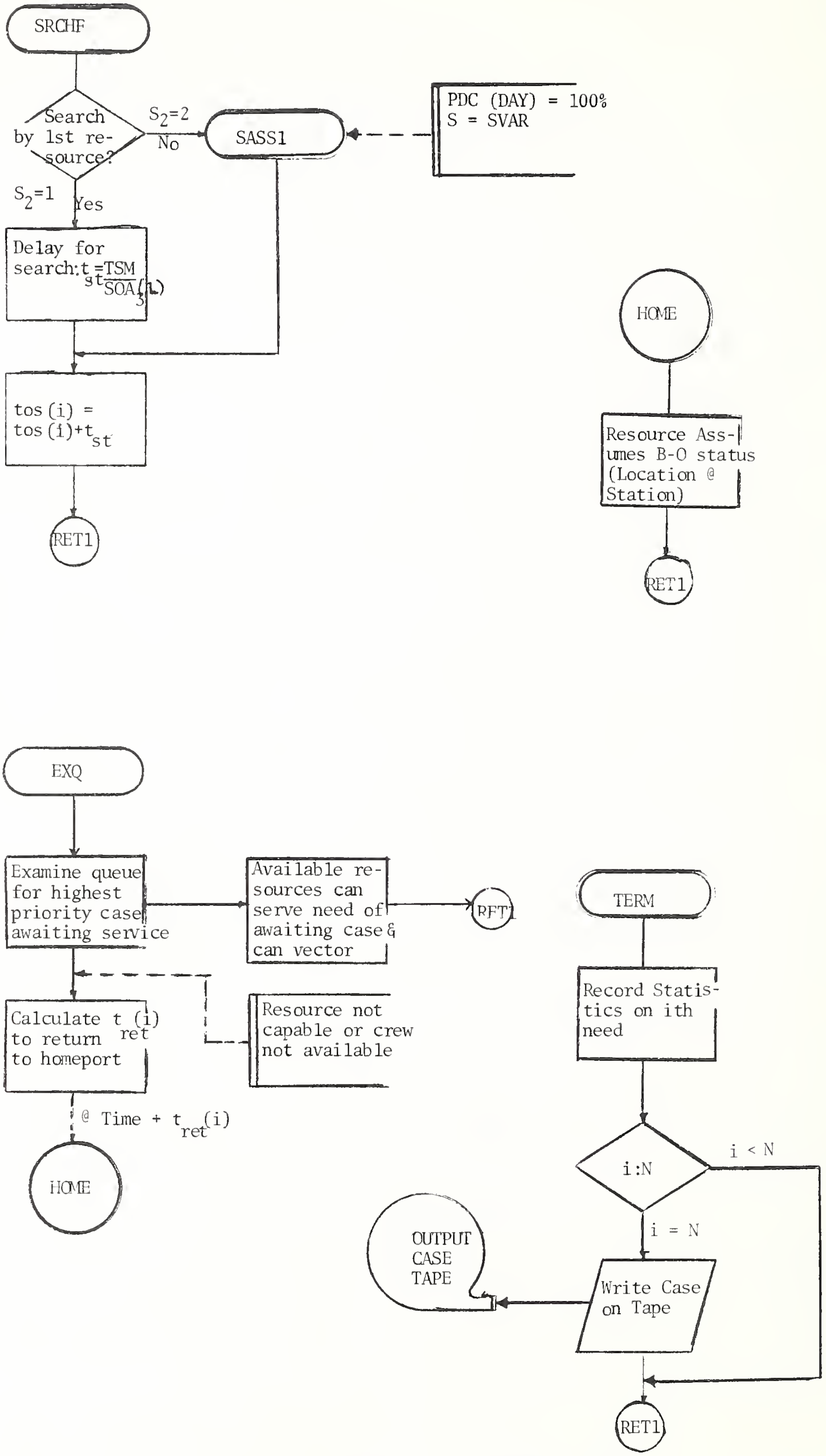


Figure 28: SRCHF, EXQ; TERM and HOME

at the completion of those needs other than tow or escort. The request for hand-off is made after the first tow or escort is satisfied. These requests are not scheduled in advance as in the situation of servicing the other needs.

If the case is a single resource air escort (i.e., the escorting resource is an aircraft), the time spent escorting, TOWTIME(i), becomes the ratio of DH, the distance between the client and his destination, to the speed of advance of the L^{th} type resource assigned to this need of the case; either SOA1(L) or SOA2(L), depending on weather conditions 1 or 2.

If, instead, the case indicates a single resource tow (or surface escort), (i.e.,the escorting or towing resource is a surface unit) then the time expended in rendering service includes the hook-up time, t_h, and the tow or escort time, TOWTIME(i) taken as the ratio of the distance DD to the towing speed, TSP. The towing speed is dependent on the client length. The hook-up time, t_h, is drawn randomly from the distribution HU, a user input. Surface escorts have been approximated by treating them as tow cases. Historically, their number is not excessive and thus the approximation is acceptable.

If the case requires a hand-off tow or escort, then the distance to the destination is divided evenly between the two needs. The hand-off point is a point halfway between the client and his destination. However, should half of the distance between the client and his destination, D2(CASE), be less than HO miles, where HO is a user input representing the minimum hand-off distance from the client's destination, then the hand-off point becomes HO miles from the client's destination. The distance off-shore is also updated relative to this hand-off point for the second tow or escort need. HO is currently considered as a quarter mile off-shore.

The time spent towing the client to the hand-off point is calculated similarly as in the single resource case. Once the hand-off point has been reached, or the single-resource tow has been completed, control is passed to RETN.

Should a tow or surface escort be interrupted by a higher priority case, the client's position is updated to where he is dropped off, and the need queued. The hand-off point is "preserved" in the case of an interrupt of a multi-resource tow. No provision is made for picking up air escort cases if the escorting resource is interrupted to serve a higher priority case.

A means of re-evaluating the severity level of the case has been provided to the user in the subroutine ONSCN. From the cumulative distribution of DRS, the direction of change in severity is determined by the Monte Carlo of the amount of unit change, IPC. In specifying the parameter KS, the user indicates that the severity is to be re-evaluated KS-1 times during the service of this need. RETN is called at the end of service of the need of the case. Since the case's severity level is expected to remain fairly constant during the service of the tow or escort need, no re-evaluation is provided when these needs are being serviced.

RETN insures continuous coverage of the case should the service of the case not be completed and the subsequently scheduled resources have not arrived on scene. (See Figure 27.) The resource already on scene will provide coverage for the client, but cannot insure coverage should a higher priority case arrive to the system and require the services of the covering resource. If a resource has arrived to serve another need of the case, and thus covers the case,or if the case is single resourced, then TERM is called, followed by EXQ and the covering resource is released. Before a resource covers a client, it examines the queue to see if it can serve a need of this case that has been previously queued. In addition, a covering resource examines the queue for a queued need of any case, every QT hours, where QT is variable.

Figure 27 illustrates RETN where coverage is provided dependent on the relationships of the arrive-on-scene time ROS(i + 1) of the (i + 1)s at resource to the leave-scene time, RLS(i), of the i^{th} resource.

Besides providing coverage to the client during the service of his needs, the resource serving the last need will serve the tow or escort needs if capable. If not, that resource will cover until resource capable of towing can arrive to scene.

As mentioned previously, short searches are handled in SRCHF if the search is done by either the first resource on scene or by an additional resource called to scene. (See Figure 28.)

SRCHF examines the S_2 code of the case and either lengthens the resource service time of the first resource on scene, so that a search can be accomplished; or passes control to SASS1, a part of the Search, Assignment and Service Subroutine, SASS. Resource selection is made in SASS1 to cover the total search miles, TSM, the first day. The severity level of the case is increased in order to model the urgency of the request for service made by the first resource on scene, and also to lower the probability that this additional resource can be interrupted.

If the search is done by the resource serving the first need, its on scene time, tos(i), is lengthened by the amount t_{st}. This can occur either directly through examination of the value of S_2 or by default, should there be no additional capable resource available when requested by the first resource on scene. In this case, the resource serving the first need will also perform the search.

The philosophy behind SRCHF is that the resource assigned to the first need was selected with regard to this need ,not for searching. Only after arrival on scene to find the client missing did the "need" for search become apparent. Thus, as is often the case, another, more suitable resource may be required to find the client.

Upon completion of service of all needs, TERM records certain of the case's statistics, removes the case from the system and files it off-line into the Output Tape*for special postprocessor analysis.(See Figure 28.) It also records the station and resource utilization statistics. Below is a list of these statistics and their definitions:

(a) <u>Case Statistics</u>

(i) COSTC: Total cost for service of the case, including the cost of a long search and the cost to vector to the expected location. In the case of a single resource or multi-resource case

---

*If opted by user.

requiring no search, the cost of servicing the case on scene for a particular need is not included. Cost is calculated in this fashion because the on-scene portion of a case (or need) other than search is relatively resource independent. The philosophy is somewhat different in selecting a resource for a long search. For these cases, the cost of covering a desired amount of search miles varies widely for different resource types. Therefore, this cost includes the cost of performing the search as well as the cost of vectoring to the scene.

The cost of the case is accumulated over all interrupts. Note also that, regardless of the cost option, COSTO (i.e., the operating cost per hour or cost ranking) selected, COSTC is calculated as above.

(ii) TSVC: The total time the case spends in the system from its arrival to its completion.

(iii) TQUE: The total time the case spends in the queue accumulated each time the case is placed in the queue.

(iv) NQUE: The total number of times a case is queued.

(v) TQUE1: The elapsed time spent in a queue prior to the first arrival of a resource to the scene.

(vi) TWAIT: The elapsed time prior to first arrival of a resource on scene. This is usually equal to the time it takes the resource to vector to the scene $t_{vec}(k)$ plus the time the client spent in queue, TQUE1, except if the case was interrupted.

(vii) CNRES: The total number of resources serving the case, including the resources assigned after the case has been interrupted.

(viii) NOINT: Number of times the case is interrupted.

(ix) TINT: Total time the case is in the interrupted state, waiting in the queue.

(x) PRI: Final priority of the case; priority is a function of severity level, which is re-evaluated during the service of the case and is updated if the case is placed in queue, or in ONSCN.

(xi) REA: The reason the case was first placed in a queue. The case can be queued for either of two reasons:

a. If there are no capable resources available at the primary and adjacent (dependent on the resource assignment policy) available at the time the case enters the system; or

b. If service is interrupted due to a case of higher priority.

(xii) RESA(i): For each i^{th} need of the case, the first resource serving that need is recorded.

(b) Station and Resource Statistics

Statistics are collected in OPSIM relative to stations and their resources. District level aggregates and averages are also derived and offered as the Standard Output, and are printed by the Report Generator.

For each resource, l, in the inventory, the average utilization index UTIL(l), is calculated as the ratio of the total number of hours throughout the simulation the resource was busy to the total time simulated.

For each station in the district the average utilization index is calculated for each shift. (The simulation allows for a maximum of eight shifts relative to a week within a given peak or non-peak season. These shifts correspond to the manning levels of the district. If, for example, the manning levels change at given times of the day, thes times dictate the shifts.) The average utilization index per station i, a per shift R, USHF (i,R), is calculated as the ratio of the total number of resource hours used to the total potential number of resource hours available during that shift, across the resources attached to station, i.

Certain aggregate statistics are found for each station i in the district. These include:

(i) The number of cases served by station i: NCAS(i).

(ii) The number of needs served by station i: NEEDS(i).

(iii) The number of interrupts at station i: NINTR(i).

(iv) The number of times a standby crew is called at station i: NSTBY(i).

(v) The number of times a standby crew was called, but not used at station i: UNPRO(i). A time delay exists between call-up and the time at which the standby arrived at the station. Therefore, a waiting case could be served by a manned resource which became available during this delay time.

Three levels of failures are defined and are recorded for each station. These include:

(i) The number of cases which came into station i where there was no capable resource in the district to serve, or failure type A FAIL1(i).

(ii) The number of cases where was no capable resource at the primary (and adjacent), or failure type B, FAIL2(i).

(iii) The number of cases where the case was not served within tolerance FAIL3(i).

Average wait time at a station is also calculated along with average utilization index. Average wait time is the arithmetic average of the values of TWAIT for those cases arriving at that station.

Average utilization index at a station i,USE(i), is calculated as the ratio of the resource hours used to the potential resource hours at station i.

Any exceptional cases are included as automatic output, and their parameters are also output. These include any cases for which no resource can satisfy a need of the case.

A district summary is provided as part of the Standard Output and includes:

(i) The total time simulated.

(ii) The total number of cases that occurred during the the total simulated time.

(iii) The total number of cases that were completed.

(iv) The total number of cases where failure type A occurred: $\sum_i$ FAIL1(i).

(v) The total number of cases where failure type B occurred: $\sum_i$ FAIL2(i).

(vi) The total number of cases where failure type C occurred: $\sum_i$ FAIL3(i).

(vii) The average utilization index across the district is calculated as the ratio of the total resource hours used to the total potential number of resource hours in the district, throughout the duration of the simulation.

(viii) For each shift, the average utilization index across the district is calculated as the ratio of the total resource hours used to the total potential resource hours in a given shift.

(ix) The total number of needs served and the total number of interrupted needs are aggregated for the district.

(x) The average time any case waits, taken as the arithmetic average of the TWAIT values across all the cases, is also calculated.

(xi) Finally, aggregates of the total number of standbys, $\sum_i$ NSTBY(i) and total number of unproductive standbys $\sum_i$ UNPRO(i) are calculated for the district.

The reader is referred to the program listings*, Report Generator Section, for a layout of these statistics.

After the collection of statistics is completed on each case, and each case's contribution to the station and resource statistics recorded, the resource is made available to those cases awaiting service in the queue. EXQ examines the queue for a waiting case at the primary station (and adjacents depending on the resource assignment policy). (See Figure 28.)

If the resource is capable and operational and a crew is available, the resource is assigned to the highest priority waiting case. If there are no waiting cases that this resource can serve, the resource is vectored home. Crew availability is assessed in exactly the same fashion as if the resource were at its home station, that is, the changes in crew manning levels over the day are taken into account. HOME is called at the time the resource has arrived at its home station. Here the status of the resource and crew is updated to idle.

If the need of the waiting case to be serviced is a search need, the remaining endurance of the resource is examined. The time to vector to scene is compared against SUNSET of that day or SUNRISE of the next day. That is, if the resource can arrive before SUNSET it

---

*Contained in Appendix B of this series, NBS Report # 10436.

is vectored. If the resource can arrive after SUNRISE of the next day, then he is vectored. Vectoring takes place only if the resource is capable, has sufficient endurance, and an available crew. Otherwise, the case remains in the queue. Recall that queued search cases are examined at SUNRISE - X hours.

A special subroutine(STNBY) examines waiting cases at the time a standby crew arrives to the station. The same logic of EXQ relative to the resources is included, but a crew is already available -- only the resources capability, endurance, etc., need be assessed.

4. POSTPRO - The PostProcessor of SARSIM

The Service Subroutine of OPSIM automatically produces the OPSIM STANDARD OUTPUT, and may also be instructed to generate an OUTPUT CASE TAPE for specialized data analyses in the PostProcessor (POSTPRO). Prepackaged data retrieval programs such as Quick Query [1/] are currently used to provide these specialized outputs. The Quick Query program was developed by C.A.C.I. and is compatible with the SIMSCRIPT language in which OPSIM is programmed.

A typical request might consist of the aggregation of all weekend cases which waited more than some specified number of hours and whose severity level was initially at some given level.

The OPSIM STANDARD OUTPUT provides statistics with reference to resource types, stations, and the district as a whole. In addition, data are printed out on any exceptional cases, that is, cases which cannot be served due to lack of a capable resource in inventory at the primary or adjacent stations (failure types A and B), or an interrupted air escort case.

Any changes to the input conditions are also listed. These changes are relative to a given base run and include the following:

(1) Any changes to the station to include additions or deletions of stations to the district; and/or changes in the station

---

[1/] "Quick Query User's Manual for Economic Development Administration", Working Paper, by Consolidated Analysis Centers, Inc., C.A.C.I., January 1970.

attributes, such as the type and number of resources; or the shift levels.

(2) Any changes in the resource types in the district inventory such as additions or deletions of types; attribute changes of each type, for example, the capability of a given type.

(3) Any changes in the resource deployment at any station, existing or new.

(4) Any changes to the crew manning levels, new or existing.

In addition to changes, the user input options relative to the PREPRO, OPSIM and POSTPRO are delineated, so that the simulation exercise can be uniquely identified.

Completed cases are filed on the Output Case Tape. The POSTPRO operates on this tape, as an option to the user, and generates additional statistics of interest to the user. This option provides flexibility of output reporting at the management and analyst levels. Having a file of completed cases, with both the input information and the status at completion,allows for a wide variety of queries to be processed.

For each case, the following information is kept.

(1) OPFAC: The historical primary station of the case. Note, this primary is assigned in PREPRO, and updated in OPSIM. The updated value is P, the primary station.

(2) NOCAS: Number of case.

(3) IDLOC: District in which the case took place.

(4) OCCUR: Date and time of case arrival to the system

(5) BOX: An indicator showing whether the case occurred during the weekday or on a weekend and either during the day or night.

(6) FPRI: The priority of the case as it enters the system.

(7) MMM: The number of tow or escort needs

(8) NNN: The total number of needs except long search and tow or escort.

(9) GAMMA: Degree of non parallel service.

(10) AIR: Air temperature at time of the case.

(11) OFSHR: Distance off-shore.

(12) VIS: Visibility

(13) WIND: Wind Force

(14) SWELL: Sea height

(15) L: Length of distressed vessel

(16) POB: Number of people on board distressed vessel.

(17) SIS: Number of resources in long search

(18) S2S: Short search code

(19) TSM: Total search miles on case

(20) UTYPE: Type of distressed unit

(21) VALUE: Value of distressed unit

(22) XCX: Original Case location

(23) YCY: Original Case location

(24) XC: Case location (Updated)

(25) YC: Case location (Updated)

(26) STATN: Reassigned primary station

(27) CNRES: Number of resources involved in a case

(28) PRI: Final case priority

(29) REA: First reason case was queued.

(30) COSTC: Total cost to serve the case

(31) ITOL: Indicator relative to case being served within tolerance

(32) NOINT: Case interrupt count

(33) NQUE: Number of times case was queued

(34) TINT: Total time in interrupt status in the queue.

(35) TQUE: Total time case spends in queue.

(36) TQUE1: Time case spends in queue prior to first resource arriving to scene.

(37) TSVC: Total time case spends in system

(38) TWAIT: Time between case occurrence and arrival of first resource

(39) NEED(i): Need of a case

(40) OST(i): Time on scene of Need (i)

(41) DELTA(i): Delay of next resourse arrival, multi-need case.

(42) RESA(i): Resource assigned to serve Need (i)

When the case includes search and or tow or escort, RESA(i) is expanded to include the resources assigned to serve these needs as well.

Using the Case Tape, with the above attributes, the user can make specialized requests. For example, an aggregation, or printout of all weekend cases which waited more than a given amount of time and had a given input severity (or priority) can provide the user with some insight as to whether his resources are strategically placed, or perhaps his manning levels need alteration. The added information of wait time broken out by severity level enhances the Standard Output relative to average station TWAIT and stand by call-ups.

APPENDIX A: Inter-District Assignment and Service Subroutine (IDASS) of OPSIM

I. Introduction

As originally conceptualized, a special submodel was developed to model the availability of the C-130 aircraft to service cases within its long-ranged capability. Simulation of cases which occurred historically external to the district were to be simulated in IDASS and served only by a C-130. Those that occurred inside the district could be served by any capable resource, perhaps a C-130, the selection being dependent on the cost option. tje statis pf tje respirces. the environmental conditions, and the case parameters.

An improved approach to handling the simulation of those cases served by the C-130 has since replaced IDASS. This discussion is in the main body, including the special preparation required to develop the case parameters for C-130 cases. The air station at which the C-130's are based is included in the list of primary stations. To prevent any other resource type from responding to the out of the district C-130 cases, this air station has no adjacent stations.

The effort required for designing IDASS and developing the computer program was well spent in that it proved to be the pilot effort in the application of the selected computer language, SIMSCRIPT to SARSIM. Since IDASS is a functioning model, but not included in the current conceptualization of SARSIM, a discussion is presented in this appendix.

SARSIM is basically designed to be exercised on the district level. Those resources assigned to each district are normally called upon to serve those cases that occur in the district. Special attention is given, however, to the C-130 since some of its characteristics, such as its long range potential and faster response, have resulted in its frequent use on an inter-district basis. Such employment of resources is an exception to the district boundary assumption. It is important, therefore, to model the availability of this resource to serve cases in the district being exercised simultaneously with all other districts using these C-130's. The major objective of SARSIM, as it is presently envisioned, is to measure the sensitivity of SAR effectiveness within each district by varying such factors as resource allowance, deployment, and case load. IDASS provides a means of including C-130's as an integral part of any CONUS coastal Coast Guard district by modeling the availability of a C-130 to service cases on an inter-district basis, concurrently with the normal work load of the district under investigation. Therefore, the Coast Guard manager has at his disposal a tool to measure the effects on each district and on each coast, of varying the number of C-130's, their work load and deployment.

II. Background and Assumptions

The Lockheed C-130 is four engine, fixed wing aircraft which is capable of proceeding 1200 NM at 290 knots to the site of a SAR incident, remain on scene for 2 1/2 hours and return to the point of origin with adequate fuel reserve. On the average, its total airborne time is approximately 12 hours.

C-130 SAR coverage for CONUS is currently provided by two Coast Guard air stations: San Francisco, California, (12th district) for the West coast; and Elizabeth City, North Carolina, (5th district) for the East coast. The East coast, insofar as C-130 availability is concerned, is comprised of 1st, 3rd, 5th, and 7th Coast Guard Districts. For the West coast, C-130's are available to the 11th, 12th, and 13th Coast Guard Districts.

Time of case notification is considered time of assigned resource departure. No warm-up or communication delays have been considered in the simulation concept at this point. These time delays can be incorporated in the model at a later date. Provisions for crew rest and refueling have been included for those flights exceeding 12 hours, and for certain interrupt situations. All flights between the 1st and 7th; or 3rd; or 8th; districts on the East coast assume an enroute refueling delay of one hour. Likewise, a similar delay appropriate for the West coast is to be included.

The number of C-130's, i.e., the allowance, available for SAR missions is adjusted to account for the effects of maintenance, crew manning levels, and non-SAR functions.

III. Special Preprocessor Required for IDASS

Before the logic of IDASS can be discussed, it is necessary to discuss the special processing required of the C-130 historical data. For each coast, a C-130 case file is prepared by examining the historical SAR workload at Elizabeth City (or San Francisco) and retaining those historical C-130 cases. (From this point, only the

East coast will be addressed to facilitate illustration of the techniques in this special processing.)

The historical C-130 case load is analyzed and the relevant distributions and parameters developed. See Figure A1 for the flow of these operations. The PCP, program to calculate case parameters, can be modified to develop these parameters; or, since there are relatively few of these cases, it may be preferable to prepare these cases manually. A distribution of time on scene also must be developed for input to IDASS. The Demand Generator can likewise be modified to generate the C-130 case load. All C-130 cases carry an extra attribute, the district where the case occurred. An additional processing step is therefore required to determine the district within which the case occurred.

The output of this special processing is a C-130 case load with the district identified where each case occurred. This output is then merged, on date and time of occurrence, with the Demand Tape for the district to be exercised. The final composite merged tape becomes the input to the Operational Simulator.

IV. Required Inputs to Operate IDASS

The required inputs for operating IDASS are similar to those described in the section in SRAS. The user inputs applicable to this subroutine include the station inputs describing the "equivalent" number of C-130's attached to the station for SAR purposes with crew manning level and maintenance factors inherent in this number. One more input required for IDASS is a matrix providing the expected vector time to arrive on scene between each pair of districts and between Elizabeth City and each district. This matrix, AOST (i, j) describing the average time of arrival to a case in district i, from district j, includes the time required to refuel, if required. An illustration of AOST (i, j) matrix is presented in Table A1. The entries shown in each AOST (i, j) cell represent the C-130 flight hours to vector to or from the weighted centroid in each of the four East Coast districts and Elizabeth City. This weighted centroid is derived from an analysis of the historical data determining a specific latitude and longitude within each district as the one most representative of where the average C-130 case occurred in that particular district.

Case Location versus Time to Vector to Scene

(Hours)

C-130 Location "j"

To District	1	3	5	7	E City
From District					
1	.5	1	2	6*	3
3	1	.5	1	5*	1
5	2	1	.5	3	1
7	6*	5*	3	.5	3
E City	3	1	1	3	0

*Assumes refuel enroute

TABLE A1: AOST (i,j)

V. IDASS Logic

The interface between the Preprocessor and the Operational Simulator, the OPSIM EXEC, determines which resource assignment subroutine to enter. As each case arrives to the system, the district in which it occurred is examined. Control is passed to IDASS for those cases outside of the district undergoing exercise. Note that a case which historically was a C-130 case occurring within the district being exercised is served in the normal fashion, as a single resource or search case. Thus, the case has an opportunity to be handled by <u>any</u> capable resource including a C-130. Similarly, cases emanating from the work load <u>not</u> historically associated with C-130's are, of course, now eligible for a C-130 assignment via SRAS, MRAS or SASS.

The flow of operations within IDASS is illustrated in Figures A2 and A3 . Briefly, IDASS simulates the assignment of a C-130 to the case and the service of that case. A resource is assigned to a case if the resource is idle at the time of arrival of the case to the system, or a resource is on a lower priority case and can be interrupted to handle the new arrival to the system. Otherwise, the case must wait in a queue for a resource to become idle and available.

<u>Step 1</u>: Refer to Figure A2. Accessing the status of each C-130, the first step is to determine if there is an idle resource at the air station (e.g., Elizabeth City). If so, control is passed to ASIN 1 which simulates the service of the case and the scheduling of crew rest and refueling, if required.

Within ASIN 1, the total on scene time, TOS, is attained via Monte Carlo and the vector time, TVEC, is retrieved from the matrix AOST (i, j); the sum of TOS and (TVEC) is added to OCCUR, the current simulated clock time, to determine the Expected Idle Alpha Time (EIAT). If the difference between EIAT and OCCUR exceeds the maximum 12 hour endurance of the C-130, crew rest and refueling is simulated; and additional sorties are required to service this case.

Control is passed to routine IS which calculates the client service time (CST), or the elapsed time the client is undergoing service (including vectoring) by the Coast Guard. In addition, the resource service time (RST) is also calculated. CST is the sum of the total on scene time, TOS; the time to vector to the scene, TVEC; and additional TVEC's to and from the scene for those cases requiring additional sorties. RST is the sum of CST and the time required to return to Bravo-Zero status at the home station (e.g., Elizabeth City). EIAT becomes the sum of the time of departure of the resource and the client service time, CST.

If no C-130's are idle at the station, step 2 is executed.

Step 2: An attempt is made to assign an idle C-130 which is returning to the air station (e.g., Elizabeth City). If there are idle-returning C-130's control is passed to ASIN 2. See Figure 25.

Within ASIN 2, the closest "idle-returning" C-130 to the case is selected. The remaining process is similar to ASIN 1. If there are no idle resources returning to the air station, then control passes to step 3.

Step 3: If the case is of a higher priority than other cases currently being served in the system, then the lowest priority case is interrupted and control passes to ASIN 3. The interrupted case is placed in the appropriate priority queue and awaits additional service on a first-in, first-out basis. Subroutine QUEUE places the interrupted case in the queue. (See the SRAS description for an explanation of QUEUE.) This new case is treated similarly as a case in ASIN 2. If, however, the new case is of a lower priority than those cases already undergoing service, it is placed in the appropriate queue to wait for a C-130 to become available, by calling subroutine QUEUE. When a C-130 becomes idle, subroutine EXQ (see SS description) examines all queues to determine which case, if any, should be served by this resource.

VI. Special Output Reporting for IDASS

Since IDASS is a macro-level simulation of the availability of C-130's to serve inter-district cases, as compared to the simulation of district cases, only, certain aggregate statistics are kept. These include: total number of C-130 cases; total client service time; total resource service time; total number of C-130 flights exceeding 12 hours. For each queued or delayed case, its time spent in the queue, its reason for delay, and its identification are recorded.

After each district has been exercised under similar conditions, and the results integrated, the Coast Guard manager will be capable of evaluating the utilization of C-130's for the coastal SAR mission.

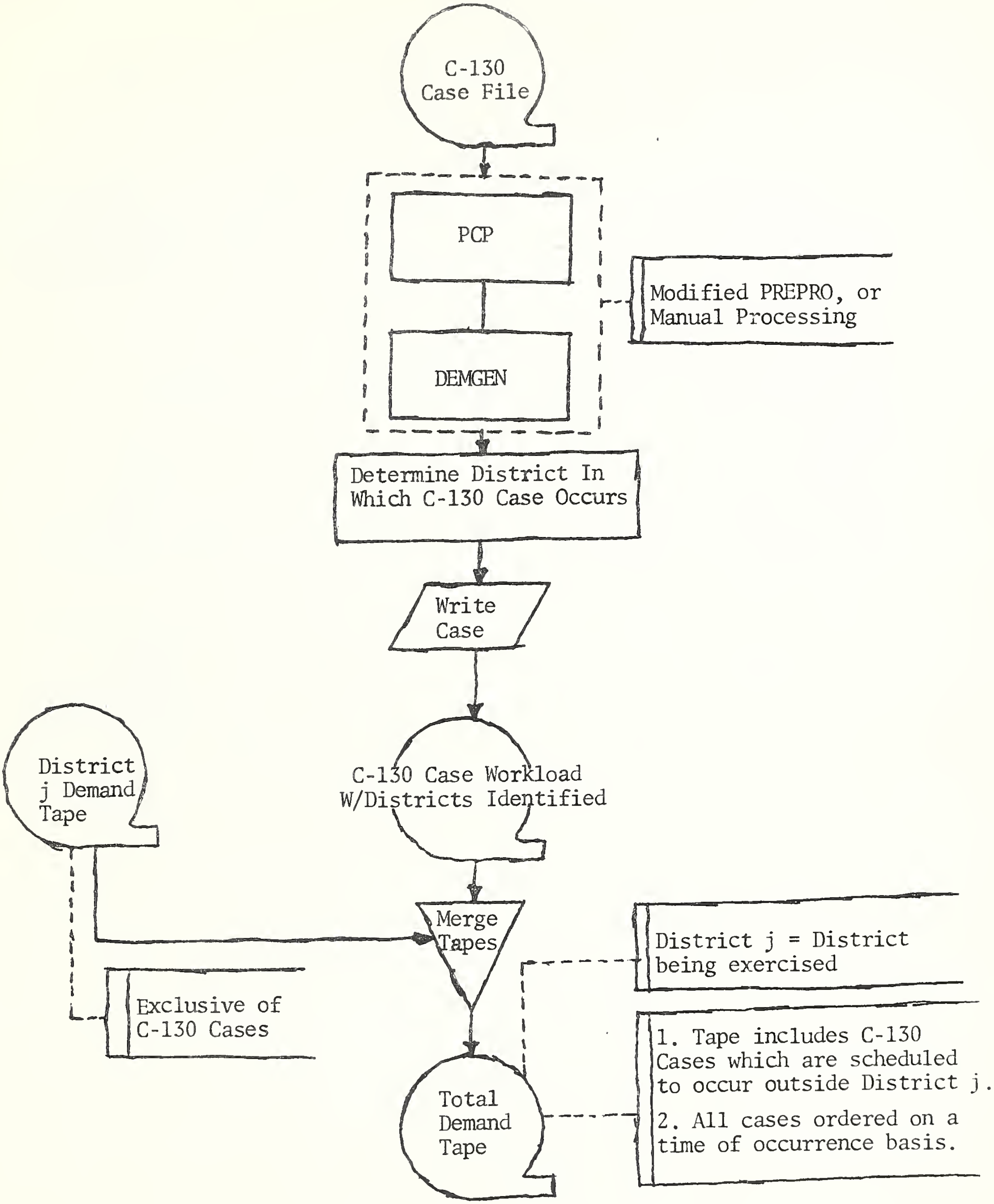


Figure A1: Special Pre-Processing for IDASS

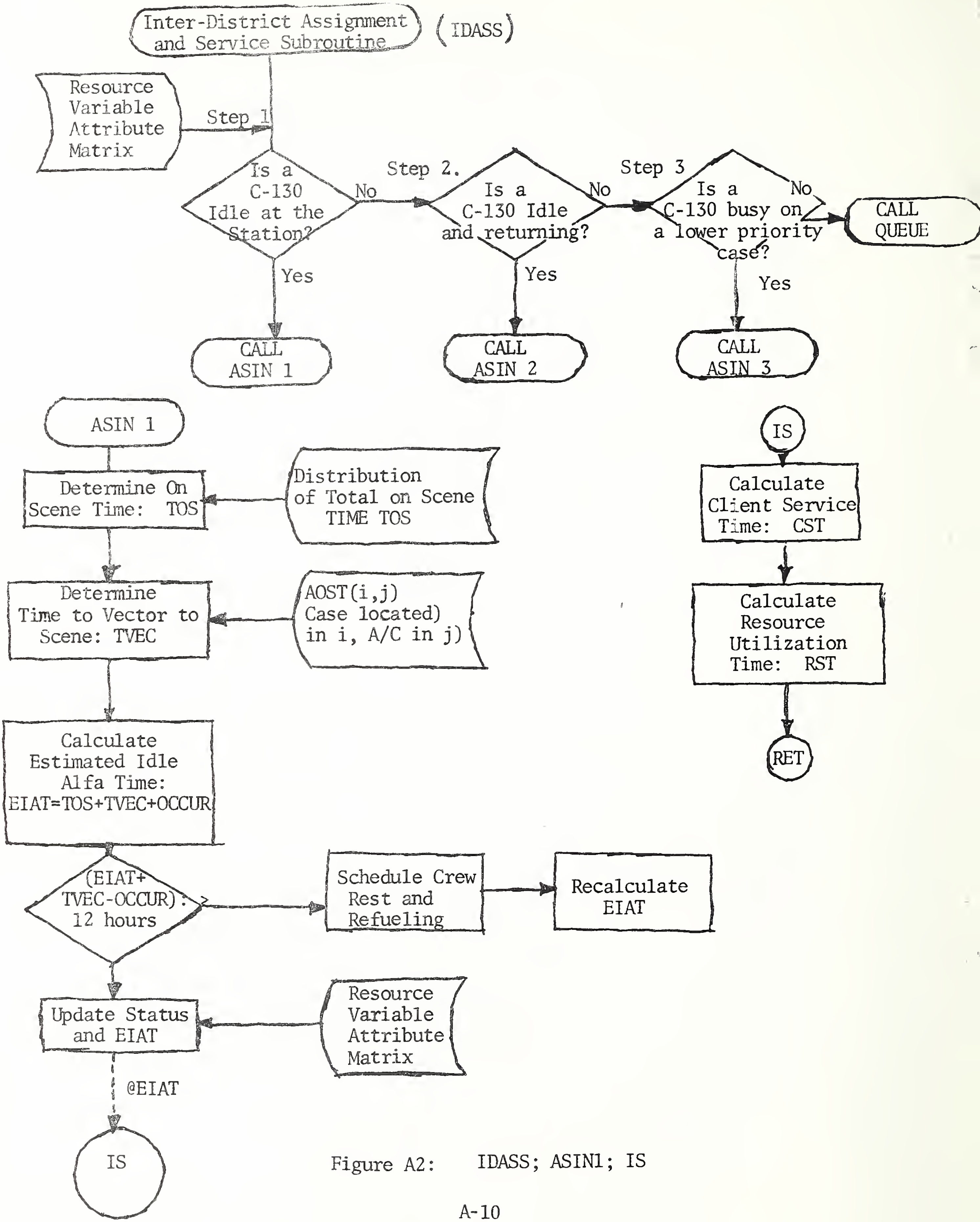


Figure A2: IDASS; ASIN1; IS

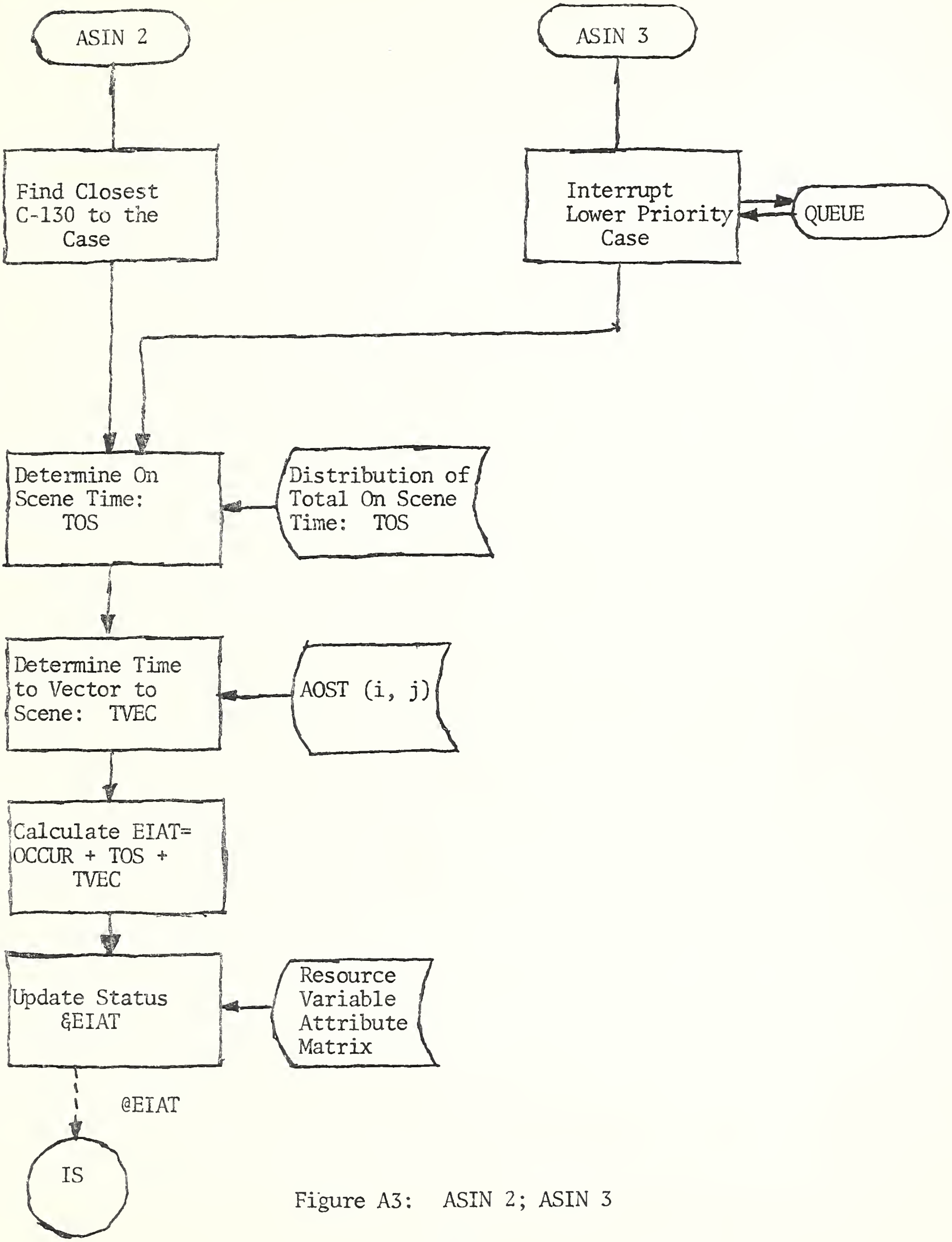


Figure A3: ASIN 2; ASIN 3

Appendix B: Glossary of Terms

A: Adjacent Station

AIA: District in which Case occurred. See IDLOC

AIR: Air temperature at time of the Case. See B6.

AOST(i,j): Vector time for IDASS from i to j.

A3: Number of Case. See NOCAS.

A4: Month and year station was notified.

B16: Type of distress area

BETA: Length in nautical miles of 1 degree of longitude at district origin

B3: People on board distressed unit

B5: Value of property involved

B6: Air temperature at time of the Case. See AIR.

C(K): Cost for each capable resource K

CL: Crew Level

D1: Assisting resource type

D3: Time resource was underway

D4: Time resource arrives on scene

D4FRST: Time resource arrives on scene time and completes search,

D6: Search time for a single resource

D6TOT: Total search time for a Case

D8: Total elapsed time underway on Case

D9: Number of sorties for a resource

D11: Assistance rendered to personnel

D12: Primary assistance rendered to property

D13: Secondary assistance rendered to property

DD: Distance and destination client is to be towed or escorted

DLAY(L): Time to get underway for resource type L

DRS: Distribution for severity level change

$\Delta(i)$: Proportion of time into case completion resource i arrived on scene

EIAT: Estimated idle alpha time - IDASS

END(L): Endurance in hours for resource type L

EOF: End of file

FLAG: Indicates if the (i-1)st resource is waiting on the ith resource

FPRI: Priority of the Case as it enters the system. Determined in PREPRO. See S.

FRST: First resource on scene begin serving a need

γ: Degree of non-parallelism of a multi-resource Case

HU: Hookup time distribution

IDELTA: Step increase of the Case priority

IDLOC: District in which Case occurred. See AIA.

INTRAP: Overide RAP switch

IPC: +1 Severity increase

-1 Severity decrease

0 No severity change

k: Index for resources
K: Number of capable resources.
KS: Number of re-evaluations to be made of the case severity, a user input

L: Index for resource types

LAST: Time last resource left scene after searching and serving need

Δij: Arrival rate, ith hour of jth time period

LVTM: Time at which resource i completes search, if any, and servicing

m: Number of tow or escort resources. See MMM

MILES: Distance off-shore. See OFSHR

MINC1: Minimum time of notification of the Case. See OCCUR and A4

MMM: Number of tow or escort resources. See m

MR: Multi-resource

n: Number of needs except search and tow. See NNN

NN: Total number of needs plus hand-off tows; $NN = n+m-1$, when $m > 0$
$NN = n$, when $m = 0$

NNN: Number of needs except search and tow. See n

NEED: Specific need of a Case

NEED(i): Need being served by ith resource

NH: Night hours if tes exceeds the number of daylight hours

NOCAS: Number of the Case. See A3

NOINT: Number of interrupts of the Case

NOTIF: Notification time of Case

NQUE: Total number of times a Case is queued

OC(L): Operating cost/hour, for resource type L

OCCUR: Date and time of Case arrival to the system. See A3 and A4

OFSHR: Distance offshore. See MILES

$$\left.\begin{array}{l}\text{Origin Latitude:}\\ \text{Origin Longitude:}\end{array}\right\}\ \text{district origin}$$

P: Primary station as defined in OPSIM

PDC(DAY): User input, percentage of SM(i) desirable to achieve,by each search resource, for the DAYth day into the search

PR(k): Percentage of SM(i) completed before SUNSET or TOLS(S) by each of the K capable resources

PRI: Priority of the Case

PRTSM (i): Fractional split of TSM as a function of S1

RLS(k): Resource leave scene = $TIME + t_{vec}(k) + t_s(i)$

REA(CASE): Reason case was first placed in queue

RNSEED: Random number seed

ROS(k): Time resource arrives on scene = $TIME + t_{vec}(k)$.

RST: Resource Service Time - IDASS

RAP(i): Resource assignment policy

S: Severity of the Case. See FPRI and PRI

S1: Average number of search resources; operating in parallel

S2: {
0 No short search
1 Short search by assigned resource
2 Short search by additional resource

SFLAG: Indicates first resource assigned to the search Case

SM(i): Number of search miles a search resource attempts to complete

SOA1(L): Speed of advance for resource type L during weather condition 1

SOA2(L): Speed of advance for resource type L during weather condition 2

SOA3(L): SOA when searching, for resource type L

SR: Single resource

STANO: Station number as defined in PREPRO

SUNRISE: User input time

SUNRISE LIST: A list of held-over search cases which are examined at SUNRISE - x

SUNSET: User input time

SVAR: Severity increase factor for short search

t_e: Elapsed time on scene serving needs

tes: Elapsed time spent searching only

$t_f(L)$: Refuel time, for resource type L

t_h: Tow hookup time (or escort delay time)

TIME: Current Simulated Clock Time

TOL(S): Tolerance for non-search use at severity level S

$t_s(i)$: Time spent on scene searching for sortie i

tos(i): On scene time for serving need i

$t\bar{o}s$: Hookup time plus tow time

TOS: Time on scene for IDASS

TOWTIME(i): Tow time for the ith towing resource; or escorting resource

TOLS(S): Search tolerance time at severity level S

$t_{ret}(i)$: Time to return to homeport

t_{sp}: Towspeed

$t_{st}(k)$: Time spent searching (total); $\frac{SM(i)}{SOA_3(L)}$, for capable resource k

TVEC: Time to vector to case IDASS

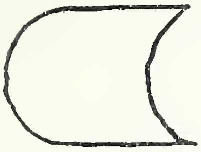
$T_{vec}(k)$: Time it takes capable resource k to vector to expected search area

TSM: Total search miles on a case

x: The hours before SUNRISE when held-over search cases are examined for resource assignment (user input)

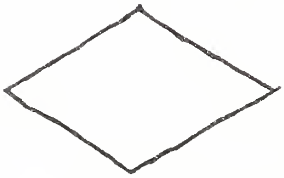
$$\left.\begin{array}{l}X:\\ \\ Y:\end{array}\right\}$$ Case Location in statute miles

Appendix C. Glossary of Flowchart Symbols

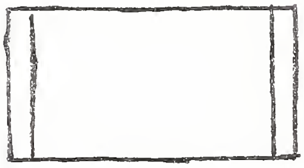
	On Line Storage
	Control is passed to a subroutine at the simulation time, STIME Control is returned to main program at present time, TIME
	Subroutine called at the simulation time, STIME
	Process
	Connector
	Return to main program
	Return to main program
	Control is passed to a subroutine at the present time, TIME

Subroutine called at present time, TIME

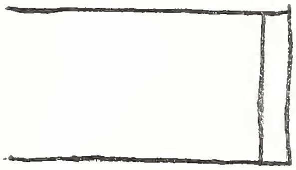
Merge information according to a given order



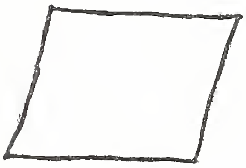
Decision



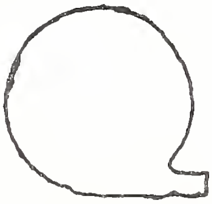
Predefined Process



Annotation



Input/Output



Magnetic Tape

DEPARTMENT OF COMMERCE * NATIONAL BUREAU OF STANDARDS *