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A COMPUTER SIMULATION
OF
NAVAL GUNFIRE SUPPORT
OF SMALL INDEPENDENT ACTION FORCES
IN AN INSURGENT-CONTESTED AREA

by

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The problem definition and results of a partial feasibility study of the Seabased Tactical Deterrent Force (STDF) concept using the simulation model are presented as a means of providing some insight into the feasibility of the STDF concept and as an example of the use of the simulation model.

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A Computer Simulation of Naval Gunfire Support of Small Independent Action Forces in an Insurgent-Contested Area

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I. INTRODUCTION

In these days of reduced U.S. Military manpower and hardware, a great deal of attention is being focused on developing the optimal military posture for future operations. One of the main factors being considered in developing this posture is the United States' announced desire to reduce the number of U.S. troops and troop support facilities on foreign soil while still maintaining the ability to respond with an adequate amount of military power to meet commitments to allied countries. Thus, a foreseeable possibility is that the U.S. might be called upon for emergency military aid to a country in which it has no land-based troops, aircraft, or artillery, as was the case in the Lebanon and Dominican Republic crises of the recent past. One of the concepts of future military posture which is under consideration is that of the Seabased Tactical Deterrent Force (STDF). Integral to the STDF concept is the concept of the Small Independent Action Force (SIAF). Each of these concepts is discussed below.

A. SEABASED TACTICAL DETERRENT FORCE

The STDF would be required to have a multitude of capabilities. Without defining all of the capabilities required, it can be summarily stated that the STDF would have to combine the existing capabilities of an Attack Carrier Striking Force, an Amphibious Task Force, a Naval Gunfire Support Force and an Underway Replenishment and Logistics

Force, while providing for its own defense as well. One of the most important requirements of the STDF, and the one which emphatically distinguishes it from other alternative concepts, would be the ability to strategically interpose combat forces in most areas in which conflicts might arise which would seriously jeopardize vital U.S. interests. This is not a new requirement, but it would enjoy renewed and expanded importance under the STDF concept. The conventional approach to exercising this capability which has been used many times in the past has been to land large numbers of troops ashore by an amphibious landing to conduct massive operations to achieve a military objective. But with changing U.S. foreign policy, such massive operations appear less likely. Also, our experience in Southeast Asia has inspired new technology and concepts of amphibious warfare. In the face of an insurgent force employing guerrilla warfare or similar tactics, massive amphibious operations are rarely practical or productive. The effectiveness of small reconnaissance and combat patrols, such as the Small Independent Action Force (SIAF) patrols, in seeking out the insurgent forces has often been demonstrated. Thus, the insertion and support of SIAF patrols becomes a capability which the STDF must have.

B. SMALL INDEPENDENT ACTION FORCE (SIAF) PATROLS

At this point in the discussion it is presumed that it has been determined that the STDF concept is a viable means of interposing U.S. military power, and the ability to insert and support SIAF patrols is organic to the STDF. The following question then arises: "What type of operations by the SIAF patrols would be most effective in a limited war situation if one arises?" Some high-ranking military officers have expressed the opinion that it might be tactically advantageous in many areas to saturate an area of limited size with SIAF patrols. These patrols would be dispersed throughout the area with the objective to either:

1. Reconnoiter an area where enemy strength and degree of control is virtually unknown, or

2. Seek out known or suspected enemy forces.

In either case, each individual patrol should typically be of short duration (a few days), small in numbers (4 to 18 men), dependent only on the STDF for logistics and external fire support, self-sustaining while actually on patrol, and capable of rapid and reliable communication with the STDF. The primary mission envisioned for the SIAF patrols would be one which is essentially passive. The patrols would seek out enemy personnel, base camps, support facilities, etc., but rather than actually engaging in combat with such targets, the patrols would call in air strikes or naval gunfire from the STDF. Thus, the mission of the patrols is primarily reconnaissance/forward observer.

C. OBJECTIVES OF THIS THESIS

In this paper, a small segment of the overall operations analysis effort required to investigate the STDF and SIAF concepts is isolated and conducted. Specifically, the subject under study is Naval Gunfire Support (NGFS), originating from the STDF, in support of SIAF's ashore in an insurgent-contested area. The objective of the paper is twofold:

1. Development of Computer Simulation Model

A computer simulation model has been developed which simulates the actions of the STDF in providing NGFS to SIAF's ashore. The model is designed primarily for investigating the queueing aspects of providing NGFS. The main focus of attention is the time interval between the time a SIAF calls for a mission to be fired and the time a ship commences firing the mission. No ascertainment is made of the actual results achieved when the mission is fired. The model is very flexible in design, allowing the simulation of a wide variety of situations defined by user-specified inputs.

2. Partial STDF Feasibility Study

After the simulation model had been developed, a typical situation in an insurgent-contested area was hypothesized, and the model was exercised to determine the optimum number and mix of various types of NGFS ships which would be required to adequately support the SIAF's ashore. Since situations in different areas certainly vary greatly and may be more or less severe than the hypothesized situation, and since the simulation is restricted solely to NGFS and no other organic capabilities of the STDF (such as air strikes), the results of the exercise cannot be considered to provide any definite conclusion concerning the overall feasibility of the STDF concept. However, the exercise provides an example of the use of the simulation model for other users to follow when a specific real-life situation is under investigation, and it also provides some insight into the feasibility of a STDF providing NGFS in support of SIAF's ashore in an insurgent-contested area.

D. ORGANIZATION OF THIS THESIS

The development and use of the model are discussed in this thesis. In the next section, the systems to be simulated are described to the degree of detail necessary to construct the simulation model. Then, the mechanics of the model are discussed in sufficient detail to allow any user with a basic knowledge of NGFS and simulation techniques to understand how the computer program works. Next, the method and results of a partial STDF feasibility study are presented and conclusions based on the results are discussed. Finally, refinements and extensions of the model are discussed.

II. THE SYSTEM

The primary system which is simulated can be identified as Naval Gunfire Support. In order to construct a realistic and useful simulation model, at least two other systems must be included in the simulation model. These are refueling and rearming of ships at sea and the conduct of SIAF patrols ashore. Each of these systems is described in this section of the paper.

A. NAVAL GUNFIRE SUPPORT

1. NGFS Ship Types

Any U.S. Naval ship with installed guns is considered capable of providing some degree of gunfire support to troops ashore. However, from among the many types of U.S. Naval ships with installed guns, the only ones which can be considered to have NGFS as one of their primary duties are cruisers (CA, CL, CLG), destroyers (DD, DL, DDG, DLG), and battleships (BB). In recent years, certain types of ships, such as the Inshore Fire Support Ship (IFS) and the Medium Rocket Launching Ship (LSMR), have been built or converted with the specific primary mission of providing NGFS. However, these ships normally do not have adequate cruising ranges and speeds to be considered as permanent elements of a STDF. There are no battleships in commission at the present time. Therefore, the only types of NGFS ships considered in the model are cruisers and destroyers.

2. Installed Guns

All cruisers and destroyers have more than one type of gun installed, but each has one type which is considered to be it's "main battery" for NGFS. For example, a heavy cruiser (CA) normally has 6 8"/55 guns, 10 5"/38 guns, and 8 3"/50 guns. However, the 8"/55 guns are considered to be the main battery and would normally be the only ones used for NGFS, while the other guns are primarily used as a backup and for self-defense in surface-to-air and surface-to-surface engagements. In the model, each ship is considered to use only its main battery for NGFS. The types of ships considered in the model and the main battery gun type of each [Reference 1] are listed below:

Cruisers		Destroyers	
CA	8"/55	DD (Fram I/II)	5"/38
CL	6"/47	DD (931 Class)	5"/54
CLG	6"/47	DDG	5"/54
		DLG	5"/54
		DL	5"/54

Throughout this paper, a CA is referred to as an 8"/55 ship, a CL or CLG as a 6"/47 ship, etc.

3. Firing Procedures

Procedures for calling for and providing NGFS vary with the specific situation and local instructions. In some situations ships might simply proceed to a firing position and fire upon a predetermined area without the assistance of spotters ashore. This is called harrassment and interdiction

(H&I) fire, but this type of fire is not envisioned in the STDF/SIAF concept. The type of firing which is most likely to occur in the STDF/SIAF situations can be considered in almost all cases to adhere to the following chronological sequence of events:

a. Call for Fire

A SIAF patrol detects a target and radios a request for NGFS to the STDF. This is referred to as a "call for fire", and will be abbreviated as CFF throughout this paper.

b. Ship Assigned

The STDF commander or his delegated subordinate determines which ship from among those available, if any are available, is most appropriate to fire the mission and assigns that ship. This assignment is based on the following factors:

(1) Range to the target,

(2) Type of the target,

(3) Distance of each ship from the firing position.

c. Assigned Ship Proceeds to Firing Position

The firing position for each mission is considered to be the point along the "gunline" which is closest to the target (the perpendicular distance from the gunline to the target). The gunline is a fictitious line in the ocean running roughly parallel to the shoreline at a specified distance from the shore.

d. Assigned Ship Sets Up for Mission

After the assigned ship has reached the firing position, it fixes its navigational position and readies its gun and then reports to the SIAF that it is ready to fire.

e. Fire the Mission

The assigned ship commences firing on a signal from the SIAF. After the first few rounds have been fired, the SIAF observes the fall of shot and radios instructions to the ship to bring fire onto the target. This is called "spotting". When fire has been adjusted onto the target, the ship continues to fire at a rapid rate until the SIAF observes that the target has been destroyed or otherwise effectively encountered. The ship then ceases fire and returns to a "ready" status.

4. Ship Operations When Not Firing

Ships assigned to NGFS duties but not actually engaged in firing would normally remain in the vicinity of the gunline in order to be able to respond rapidly when assigned to fire a mission. The specific area in which non-firing ships would operate would be specified by the STDF commander. A frequently used procedure is for non-firing ships to operate on or inside of a race-track type waiting pattern at a distance from the gunline determined by considering the tradeoffs between rapid response time and the need to keep non-firing ships out of range of suspected enemy shore batteries.

B. REFUELING AND REARMING

A definite limitation on the availability of NGFS ships is imposed by fuel and ammunition capacities of each ship. Under normal steaming conditions, a destroyer with a full load of fuel can steam for 3 to 4 days before it will be required to refuel, while a cruiser can steam 5 to 6 days. This assumes that refueling is required when the amount of fuel on board reaches 50% of ships capacity, a fairly common criterion. To determine when rearming is required, the STDF commander would normally specify a minimum on-board ammunition level to which ships would be allowed to fall before rearming. This level would be a function of the type of ship, expected rate of fire, and number of other ships present.

It is possible that refueling and rearming requirements would not impose a limitation on NGFS provided. This would be the case when other NGFS ships are available to temporarily replace ships which are required to refuel or rearm, or when the duration of the operation is short enough that rearming and refueling should not be necessary.

C. SIAF PATROL PROCEDURES

A very detailed computer simulation model of SIAF patrol actions has been developed by TRW, Inc. of Los Angeles and is described in detail in Reference 2. This model can be used for developing optimal patrol procedures and for determining expected patrol results for a wide variety of friendly and enemy situations. In the model described in this thesis, no attempt has been made to simulate specific patrol actions with the exception of patrol insertion, calls made to the STDF for NGFS, and patrol extraction. Under the STDF concept, a SIAF patrol would typically adhere to the following chronological sequence of major events:

1. Insertion

The patrol is inserted into its assigned subarea of the overall objective area. This insertion would normally be accomplished by helicopter from an LHA assigned to the STDF, but could conceivably be accomplished by other means such as paradrop or amphibious landing. Order and time of insertion into the various subareas would be chosen such as to yield the highest probability of achieving a tactical advantage by surprising and confusing the enemy.

2. Patrol Maneuvers

The SIAF patrol maneuvers within its assigned subarea attempting to locate the enemy and his support facilities while remaining undetected by the enemy. When targets are located the patrol calls for NGFS or air strikes, if available, rather than actually engaging in combat with the enemy. The patrol would continue to maneuver within its assigned subarea until extracted for one of the three reasons indicated below.

3. Extraction

The patrol is extracted when one of the following occurs:

a. A predetermined extraction time is reached.

b. The patrol leader considers that optimal area coverage has been achieved.

c. Extraction is required because the patrol's effectiveness has been significantly reduced by personnel casualties.

Extraction would normally be accomplished by helicopter.

D. THE ENEMY SITUATION

Obviously, the enemy situation is a factor which plays a large role in any study of NGFS and SIAF patrols. No study could ever begin without a reasonably accurate estimation of the size of the enemy force, its locations, its capabilities, and its expected actions. These enemy factors and others are considered in great detail in the TRW SIAF model. They are considered in the model described in this paper in the following ways:

1. Subarea Division

Division of the objective area into patrol subareas is based on terrain features, expected enemy locations, and expected number and capabilities of enemy in each subarea.

2. Call-for-Fire Rate

The real cornerstone on which the model depends for accurate estimates of the queueing aspects of NGFS is the expected rate of calls for fire in each subarea. This rate is, of course, primarily dependent on the enemy density in each subarea. For a specific situation, the CFF rate for a particular subarea can be closely estimated by the TRW SIAF model or can be predicted based on available intelligence.

E. ASSUMPTIONS

There are several general assumptions which are necessary in modeling NGFS within the scope of this paper. These are discussed below. While each of these detracts from the realism of the model, it is considered that none of them significantly detracts from the accuracy of queueing results. Other more specific assumptions will be discussed as they occur in the description of the model in Section III.

1. SIAF patrols remain within their assigned subarea throughout the time interval between insertion and extraction, and only detect targets in their assigned subarea.

2. The enemy situation at the start of the operation in each subarea remains the same throughout the operation.

3. The enemy does not launch attacks against NGFS ships, or if he does the attacks are not successful enough to significantly reduce the operational capability of the ship.

4. SIAF patrols do not come under enemy attack, or if they do the attack is such that emergency NGFS is not required and the patrol's capability is not seriously reduced.

5. A SIAF patrol remains stationary at the same point from the time it has called for a mission until the mission

is complete. This leads to the further assumption that patrols spot only one target at a time, i.e., while one mission is in progress the patrol does not detect any other targets.

6. When a SIAF patrol is extracted from its assigned subarea, another patrol is not inserted into the area to replace the extracted patrol.

7. SIAF patrols do not sleep; at least, no element of the model specifically simulates a period of time during which patrols are sleeping. However, it can be considered that unusually long interarrival times between missions in a particular subarea could be caused in some instances by a period of time during which the patrol in that subarea is sleeping.

III. THE MODEL

This section describes the model which has been developed to simulate the systems described in Section II. The simulation program is written in FORTRAN IV. It is not the intent of this section to describe the entire program step-by-step; but rather to describe the mechanics of the program in sufficient detail to allow any user with a basic knowledge of NGFS and computer simulation techniques to understand what is being simulated and to be able to use the model according to his own input parameters, or to adapt certain sections of the program, if desired. A generalized flow chart of the program is contained in Appendix A and the complete program listing is contained in Appendix B. Numerous comment cards have been included in the program listing to facilitate understanding.

A. PRELIMINARY DISCUSSION

1. Variable Names

Mnemonic variable names are used throughout the program to facilitate association between the names and the quantities which they represent.

2. Measures

All times in the program are measured in whole minutes and distances are measured to the nearest whole yard, unless otherwise indicated. In view of these measures, all variables beginning with A through W are declared to be 4-byte integers. Whenever a calculation of an integer-valued time quantity is performed, 0.5 is added to the result, resulting in a truncated integer accurate within ±.5 minutes.

3. Input Data-General

Almost all numerical quantities used in program calculations are read in at the beginning of the program from a data deck prepared by the user. The definition and use of each input variable is discussed as it appears in the model description which follows. A detailed guide to assembling the data deck is included in Section III.J.

4. Random Numbers

There are 14 points in the program at which random numbers are used for Monte Carlo-type comparisons or calculations. Random number streams at each point are independent of all other points in the program. The random number generator is initialized by specifying any 14 odd five-digit numbers as input variables IR1 through IR14. KR is set equal to 65539 at the beginning of the program. Random numbers are then produced by the following calculation at each point a random number is required (IR1 is used for example):

```
IR1 = IR1 * KR
XRN = 0.5 + FLOAT(IR1) * 2.328306E-10
```

XRN will be a floating point random number uniformly distributed between 0.0 and 1.0 [Reference 3].

5. Ship Identification

Throughout the program ships are referred to by their type (T) and ship number (S). The four types of ship and corresponding values of T are:

1 = 8"/55 ship (cruiser)

2 = 6"/47 ship (cruiser)

3 = 5"/54 ship (destroyer)

4 = 5"/38 ship (destroyer).

A maximum number of 9 ships of each type are provided for, or a maximum of 36 ships. The number of each type of ship "present in the problem" is specified by the input variables NR855, NR647, NR554, and NR538. "Present in the problem" refers to the number of ships present at the start of the problem. The names of quantities which are related to a particular ship are subscripted by the ship number and type in that order, i.e., UTIL (5,2) is the cumulative total minutes that 6"/47 ship #5 has been utilized for NGFS.

6. Uniform Distributions

There are several points in the program where observations of a random variable from a uniform distribution are made. In each case, the observations are generated by use of the following formula:

RV = MIN + XRN * (MAX - MIN) .

where RV is the random variable being observed, XRN is a random number between 0.0 and 1.0, and MIN and MAX are the parameters of the uniform distribution.

7. Number of Iterations

The user specifies the number of iterations of the problem which he desires to use to obtain averaged results.

This number is specified as the input variable NRIT. In several trial runs of the program, NRIT = 10 was shown to be sufficient for obtaining reliable results with a relatively narrow 95% confidence interval. However, increasing NRIT will reduce the width of the confidence interval even further.

8. <u>Specification of Card Reader and Printer Logical Unit Numbers</u>

All READ and WRITE statements in the program use the values of the variables R and W as the card reader and printer logical unit numbers, respectively. As written, the program specifies R = 5 and W = 6 at the beginning by the statement DATA R,W/5,6/. If the card reader and printer logical unit numbers at a computer facility on which the program is to be run are not 5 and 6, respectively, then the above DATA statement must be replaced by one which specifies the appropriate logical unit numbers.

B. PROBLEM AREA

The first step in developing data for the model is to define the problem area in terms of a coordinate system which can be specified to the computer.

1. <u>Objective Area (OA)</u>

The OA is the overall area ashore in which SIAF patrols are conducted. The OA is divided into NRAREA patrol subareas, where NRAREA is an input variable specifying the number of subareas. NRAREA must be between 2 and 50. These subareas must be rectangular and the boundaries of each subarea must be parallel or perpendicular to the boundaries of all other subareas, and the northern and southern boundaries of each subarea must be parallel to the gunline. For purposes of uniformity it is considered that all subarea boundaries run north to south and east to west. The western edge of the westernmost subarea is considered to be the y-axis of an x-y coordinate system (see Section III.B.3 for exception). The distance of the eastern and western edges of each subarea from the y-axis are the input variables EAST(NR) and WEST(NR), where NR is the subarea number. Subareas may be numbered in any way desired by the user.

2. Gunline

The gunline is a fictitious straight line in the ocean, parallel to a straight line oriented east-west which approximates the shore line. See Section II.A.3.c for a definition of the gunline. The gunline is considered to be the x-axis of the x-y coordinate system. The distance of the northern and southern boundaries of each subarea from the gunline are the y-coordinates of the subarea, specified by the input variables NORTH(NR) and SOUTH(NR). The y-coordinate of the northern edge of the northernmost subarea must be greater than the maximum range of the longest gun present.

3. Waiting Pattern

The area in which ships operate while not assigned to a mission is defined by the user by appropriate specification of values of the following input variables:

WTDIS - Perpendicular distance of the northern edge of the waiting pattern from the gunline

NSWAIT - The north-south length across the waiting pattern

WTNW and WTNE - The perpendicular distance of the western and eastern edges, respectively, of the waiting pattern from the y-axis. (NOTE: If the western edge of the waiting pattern is west of the western edge of the OA, then the western edge of the waiting pattern should be used as the y-axis (WTNW = 0)).

4. Justification of Problem Area Definition

It is realized that the scheme of problem area definition described above does not exactly conform to most real-life situations. For example, area boundaries would often conform to rivers or treelines and not necessarily be straight lines. However, straight line approximations such as used in this model should not significantly effect the queueing results if input variables are properly specified.

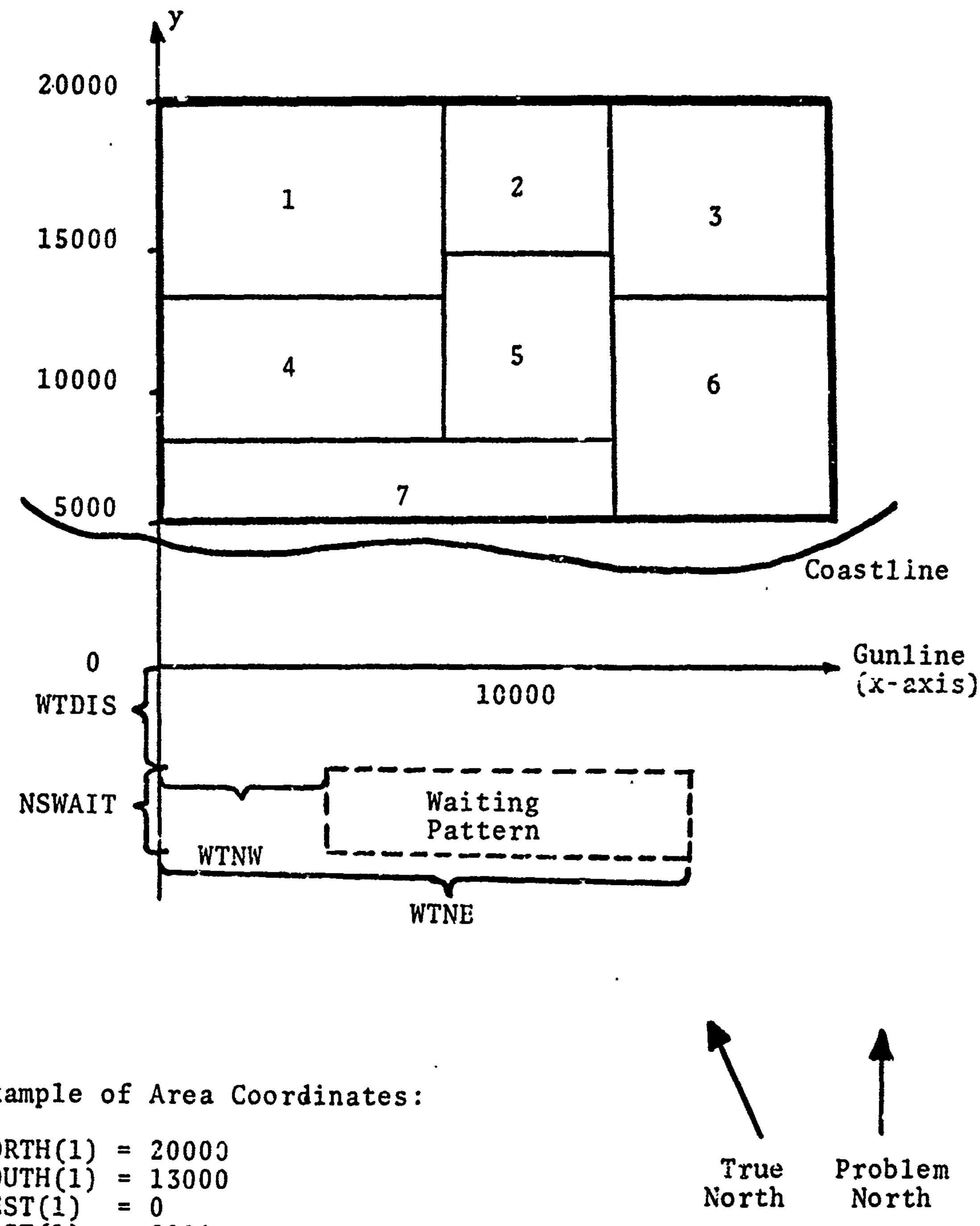
Figure 1 illustrates a typical problem area defined in the coordinate system described in this section.

C. EVENT CHAIN AND MISSION SCHEDULE

The two principle mechanisms by which data is kept track of and program control is exercised are the "Event Chain" and the "Mission Schedule".

1. Event Chain

The simulation uses the "next-event" method of time advance. At the beginning of the problem the statements K = 1 and CLOCK = EVENT(K) sets the problem timer to the time



Example of Area Coordinates:

NORTH(1) = 20000
SOUTH(1) = 13000
WEST(1) = 0
EAST(1) = 8000

Figure 1. Typical Problem Area Map.

of the first event. This event is then directed through its appropriate path of logic. When it has been completely processed the value of K is increased by 1 and the time is advanced to the time of the next event. This process is continued until an event with a time of 9999999 is the next event and the problem is terminated. Such an event is created when the generated time of the next call for fire in a subarea is greater than the time of extraction of the patrol from that subarea.

a. Event Types

There are four types of events considered in the program. These are indicated by the value of the variable EVTYP(K) as follows:

1: A call for fire from a SIAF patrol

2: A NGFS mission completion

3: A scheduled refueling of a NGFS ship

4: A completion of refueling, rearming, or combined refueling/rearming of an NGFS ship.

b. Event Parameters

The Event Chain actually consists of four parameters associated with each event. These are stored in vector arrays with variable names as follows:

EVENT(K): Time of K^{th} event (minutes from zero problem time)

EVTYP(K): Type of K^{th} event (values IAW Section III.C.1.a)

EVTMSN(K): If EVTYP(K) = 1 or 2, then EVTMSN(K) is the mission number of the K^{th} event. Mission numbers are assigned in chronological order (see next subsection). If EVTYP(K) = 3 or 4, then EVTMSN(K) = 0.

REPSHP(K): If EVTYP(K) = 1 or 2, then REPSHP(K) = 0. If EVTYP(K) = 3 or 4, then REPSHP(K) is a two digit number representing the number and type of the refueling and/or rearming ship, i.e., REPSHP(K) = 23 means 5"/54 ship #2 is either scheduled to refuel or has completed refueling and/or rearming.

c. Subroutine VENTCH

Each time a new event is generated in the program subroutine VENTCH is called. The arguments of VENTCH are the four parameters discussed above. S/R VENTCH inserts the new event into its proper chronological order on the event chain, and increases the event number of all suceeding events by 1.

2. Mission Schedule

The mission schedule represents a chronological listing of all NGFS missions which have been generated during the problem.

a. Mission Generation

A call for fire represents a mission arrival. In view of assumption 5 in Section II.E., mission interarrival times are represented by the time interval between the time the last mission in a particular subarea was completed and the time of the next mission arrival in that subarea. Mission interarrival times in each subarea are assumed to be exponentially distributed with a rate which is indirectly specified by the user in the following manner: For each subarea, the minimum and maximum expected patrol duration (number of days from insertion time to the nearest tenth) are specified by the user as the input variables XSHORT(NR) and XLONG(NR). The program calculates expected patrol duration as

$$XDURAT(NR) = (XSHORT(NR) + XLONG(NR))/2.$$

For each subarea, the user also specifies the expected number of calls for firing during a patrol (i.e., during the time XDURAT(NR)), as the input variable XCFF(NR). Then the program calculates the call-for-fire rate for each subarea as

$$XCALRT(NR) = XCFF(NR)/(XDURAT(NR) * 1440)$$

where the factor 1440 converts days to minutes. The arrival rate then has units of calls/minute.

Exponentially distributed interarrival times are generated as follows [Reference 4]:

The cumulative distribution function for the exponential distribution is

$$F(x) = 1 - e^{-\lambda x}$$

where x is an interarrival time and λ is the arrival rate. Since F(x) is a continuous probability between 0.0 and 1.0 it can be replaced by a random number between 0.0 and 1.0, say r. Then

$$r = 1 - e^{-\lambda x} \Longrightarrow x = -(1/\lambda)\ln(1-r)$$

or equivalently

$$x = -(1/\lambda)\ln(r).$$

Thus, -ALOG(XRN)/XCALRT(NR) is an exponentially distributed interarrival time of a call for fire in subarea NR. There are two points in the program at which calls for fire are generated.

(1) First Mission. At the start of the problem, the time of the first mission to be called for in each subarea is calculated as

FIRST(NR) = INSERT(NR) - ALOG(XRN)/XCALRT(NR) + 0.5

where INSERT(NR) is the time of patrol insertion into subarea NR in minutes from zero problem time. INSERT(NR) is an input variable specified by the user. Zero problem time is defined as the number of minutes after midnight on the first day of the problem that the first partrol is landed in its assigned subarea. It is specified by the input variable HHOUR. The value of HHOUR is used in the program only to convert times of calls for fire and mission completion to date-time-groups in the Mission History printout.

These first missions are then placed on the mission schedule by setting MSNSKD(I) = FIRST(I) and arranging the elements of MSNSKD in chronological order by a "ripplesort" technique. The first missions are then placed on the Event Chain with parameters EVENT(K) = MSNSKD(I), EVTYP(K) = 1, EVTMSN(K) = I, and REPSHP(K) = 0.

(2) Next Missions. Each time a mission is completed, the time of the next call for fire in that subarea is calculated as

NEXT = CLOCK - ALOG(XRN)/XCALRT(AREA(E)) + 0.5

where CLOCK is the present value of the problem time and AREA(E) is the subarea in which the mission was just completed. This mission is then placed on the mission schedule by a routine which is similar to VENTCH but which is not a separate subroutine since it is only used at this one point in the program. Next missions are also placed on the Event Chain with appropriate parameters.

b. Mission Parameters

As with the Event Chain, the Mission Schedule actually consists of 19 parameters which are assigned to each mission. When a mission is first generated it is only assigned 2 parameters, MSNSKD(I) and AREA(I). The other 17 parameters are assigned at various points in the program after CLOCK time has reached the time of the call for fire for the I^{th} mission. A discussion of each of the vector arrays in which these 19 parameters are contained and the way in which each is assigned follows:

(1) MSNSKD(I): Time of call for fire for the I^{th} mission (minutes from zero problem time)

(2) AREA(I): Number of the subarea in which the I^{th} mission occurs

(3) RANGE(I): Range from the firing position to the target of the I^{th} mission (the target's y-coordinate)

(4) EWTAR(I): East-west coordinate of the target of the Ith mission (the target's x-coordinate)

Although target densities vary in different subareas, targets are considered to be uniformly distributed within each subarea. Therefore the target coordinates are calculated as uniformly distributed random variables between SOUTH(A) and NORTH(A) for RANGE(I), and WEST(A) and EAST(A) for EWTAR(I), where A = AREA(I).

(5) TYPE(I): Type of target of the Ith mission

There are four target types considered in the problem. These are:

1: Many personnel (20 or more) or personnel widely dispersed.

2: Few personnel not widely dispersed.

3: Heavy material objects (large bunkers, tanks, heavy artillery, etc.).

4: Light material objects (small bunkers, jeeps, etc.).

The probability of each type of target (i.e., the estimated percentage of all targets in the subarea which are of each type) for each subarea is specified by the user by the input variables XPROB1(NR), XPROB2(NR), XPROB3(NR), and XPROB4(NR). The sum of these four variables must equal 1.0 for each subarea. When a call for fire occurs, a random number is generated and compared with the cumulative target type probability distribution for the area in which the mission occurs to determine the target type.

(6) MISTYP(I): Mission type of the I^{th} mission. This type refers to the types of ships which may be assigned to fire the mission, as will be discussed in Section III.D.

(7) TYPSHP(I): Type of ship assigned to fire the I^{th} mission.

(8) SHIPNR(I): Number of the ship assigned to fire the I^{th} mission.

The ways in which parameters (7) and (8) are assigned are indicated in Sections III.E. and III.F.

(9) TRAVEL(I): The time interval between the time a ship is assigned to fire the I^{th} mission and the time the ship arrives at the firing position.

(10) SETUP(I): The time interval between the time the assigned ship arrives at the firing position and the time the first round is fired.

(11) FIRE(I): The time interval between the time the first round is fired and the time the last round is fired.

(12) SERVC(I): Total service time of the I^{th} mission. SERVC(I) = TRAVEL(I) + SETUP(I) + FIRE(I).

(13) AMMEXP(I): Number of rounds of ammunition expended in firing the I^{th} mission.

Parameters (9) through (13) are all computed by subroutine SERVIC, which will be discussed in Section III.G.

(14) FSTSHT(I): The time between the call for fire and the time the first round was fired for a mission which required no queue time. FSTSHT(I) = TRAVEL(I) + SETUP(I).

(15) FSTSHO(I): Same as FSTSHT(I) for a mission which required queue time. FSTSHO(I) = QTIME(I) + TRAVEL(I) + SETUP(I).

(16) JOINQ(I): The time the I^{th} mission joined the queue. JOINQ(I) = 0 if the I^{th} mission required no queue time.

(17) LEAVEQ(I): Time the I^{th} mission left the queue. LEAVEQ(I) = 0 if the I^{th} mission required no queue time.

(18) QTIME(I): Amount of time the I^{th} mission was required to wait for assignment of a ship to fire the mission (queue time). QTIME(I) = LEAVEQ(I) - JOINQ(I).

(19) MSNCMP(I): The time at which the I^{th} mission was completed. MSNCMP(I) = MSNSKD(I) + QTIME(I) + SERVC(I).

D. SHIP ASSIGNMENT DOCTRINE

1. Types of Ship Assignment Doctrines

There are two types of ship assignment doctrine available to the user. These refer to the decision process which the STDF commander uses to determine which types of ships from among those "present in the problem" are appropriate to fire a particular mission. The type of ship assignment doctrine is specified by the input variable ASNDOC, which has values defined as follows:

1: "Any ship with guns of adequate range may fire." The target range is the only consideration in determining which types of ships are appropriate to assign to fire the mission.

2: "Best effect on target." Both target range and target type are considered in determining which types of ships are appropriate to assign to fire the mission.

When ASNDOC = 2 is used, the following rules govern the determination of appropriate ships:

1. Heavy material targets (type 3) may only be fired at by 8"/55 or 6"/47 ships, unless there are no 8"/55 or 6"/47 ships present in the problem or there are no 8"/55 ships present and the target is out of range of a 6"/47 gun. The reason for this rule is that 8"/55 and 6"/47 shells have a considerably higher explosive power than 5"/54 or 5"/38 shells.

2. Personnel targets (types 1 or 2) may only be fired at by 5"/54 or 5"/38 ships and a 5"/54 ship is preferrable due to its rapid rate of fire, unless there are no 5"/54 or 5"/38 ships present, or the target is out of range of a 5"/54 gun, or there are no 5"/54 ships present and the target is out of range of a 5"/38 gun.

2. Mission Types

Regardless of which assignment doctrine is used, each mission is assigned a mission type number (MISTYP(I)). This number indicates what types of ships, from among those present in the problem, are appropriate (eligible) to fire the mission. There are 8 possible values of the variable MISTYP(I), as follows:

MISTYP(I)	Type Ships Eligible to Fire
1	8"/55
2	8"/55, 6"/47
3	5"/54
4	5"/54, 5"/38
5	Any
6	8"/55, 6"/47, 5"/54
7	8"/55, 5"/54
8	None

3. Maximum Gun Ranges

The maximum range of each type gun in the problem is specified by the user as the input variables MAX855, MAX647, MAX554, and MAX538. The maximum range of the longest type of gun present is also specified by the input variable MAXNGF. Due to the construction of the model there are two requirements on these quantities:

1. MAX855 $\leq$ MAX554 $\leq$ MAX647 $\leq$ MAX538, unless no ships of a particular type are present (i.e., if NR554 = 0, then MAX554 = 0).

2. $\text{MAXNGF} \leq \max_{\text{NR}} \{\text{NORTH(NR)}\}$

In view of the first requirement, the only type of missions which will occur if ASNDOC = 1 are 1,5,6, and 7. Any of the types 1 through 7 may occur if ASNDOC = 2. A type 8 mission will never occur if the second requirement is satisfied. If a type 8 mission does occur, the message "A TYPE 8 MISSION HAS OCCURRED IN AREA____" will be printed out and the program will terminate.

4. <u>Warning Concerning Use of Ship Assignment Doctrine 2</u>

Assignment doctrine 2 has one definite shortcoming. It only considers which types of ships are present in the problem, not which types are available to fire at the time the mission is called for. Thus, a situation could occur in which the only types of ships appropriate to fire a mission are off-station for rearming or refueling at the time the mission is called for. Then the mission would be required to wait until one of these ships returns before it is fired although other ships with guns of adequate range might be available probably, resulting in an unacceptably large amount of queue time.

E. SHIP AVAILABILITY

After a mission has been assigned a mission type in accordance with the rules of the specified assignment doctrine, subroutine AVAIL is called once for each type of ship which is eligible to fire the mission and present in the problem. The arguments of AVAIL are the number of ships present of the type being considered, and the type of ship being considered.

1. <u>Ship Status</u>

The status of each ship in the problem is maintained by the variable STATUS(S,T), where S is the ship number and T is the ship type. There are four possible values of STATUS(S,T), as follows:

1: Ship available for assignment.

2: Ship presently assigned to a mission.

3: Ship presently refueling, or in a "refuel after mission" status, or engaged in a combined refueling/rearming.

4: Ship presently rearming.

2. Vector of Available Ships

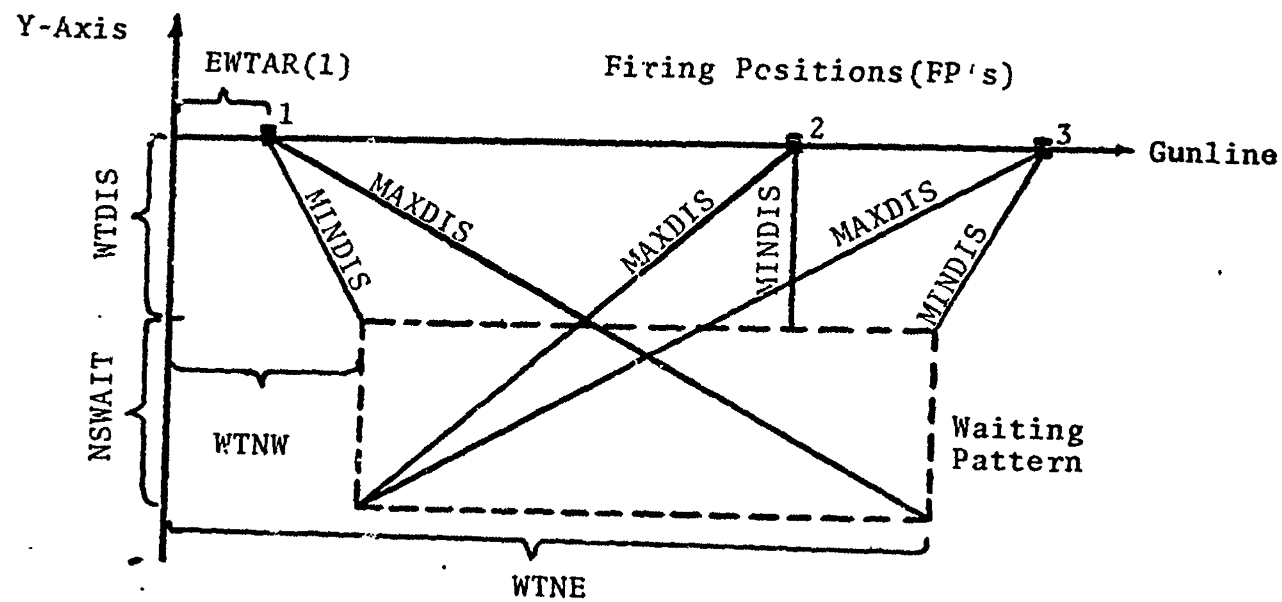
The series of calls on AVAIL for each mission results in a vector (VAIL) of ships of types appropriate for the mission for which STATUS(S,T) = 1. The values in this vector are two-digit numbers with the ship number as the first digit and ship type as the second digit. For example, VAIL(1) = 23 means that the first ship checked which was available was 5"/54 ship #2. S/R AVAIL also keeps a tally of the number of ships which are available to fire the mission. This tally is the value of the variable KOUNT.

3. Assignment of Closest Ship

After the vector of available ships is obtained by calling AVAIL, control is returned to the main program. If KOUNT = 0, the mission joins the queue. If KOUNT > 0, then the distance of each ship in the vector VAIL from the firing position is determined in the following manner:

Each available ship is considered to be at some random point in the waiting pattern. For each ship, its distance from the firing position is calculated as a uniformly distributed random variable between the minimum possible distance (MINDIS) and the maximum possible distance (MAXDIS). The method of calculation of MINDIS and MAXDIS is indicated in Figure 2.

The closest ship is then assigned to fire the mission. This is done by the following calculations:



To FP 1: $MINDIS = \sqrt{WTDIS^2 + (WTNW - EWTAR(1))^2}$

To FP 2: $MINDIS = WTDIS$

To FP 3: $MINDIS = \sqrt{WTDIS^2 + (EWTAR(3) - WTNE)^2}$

To all 3 FP's:

$$MAXDIS = \sqrt{(WTDIS+NSWAIT)^2 + [MAX(WTNE-EWTAR(I),EWTAR(I)-WTNW)]^2}$$

Figure 2. Method of Calculation of MINDIS and MAXDIS.

TYPSHP(I) = MOD (VAIL(JD), 10)

HULLNR(I) = VAIL(JD)/10

where JD is the position in the vector VAIL of the closest ship.

F. THE QUEUE

The queue in the model consists of those missions for which the time of call of fire is less than the current problem time (MSNSKD(I) < CLOCK) but to which a ship has not yet been assigned. Thus, missions in the queue are referred to as "awaiting assignment".

1. Joining the Queue

A mission joins the queue when no ship appropriate for the mission type is available at the time the mission is called for (KOUNT = 0). Mission numbers of missions awaiting assignment are maintained in the vector Q. The current number of missions awaiting assignment is maintained by the variable INQ. In view of the assumption stated in paragraph II. D.5, the maximum possible number of missions in the queue is equal to the number of patrol subareas.

2. Leaving the Queue

A mission leaves the queue when an appropriate type ship becomes available by having completed another mission or having completed refueling and/or rearming, and there are no other missions ahead of it in the queue which are waiting for the same type of ship. Each time a ship becomes available and INQ > 0, each mission in the queue, beginning with

Q(1) is checked to see if the available ship is appropriate to that mission. As soon as one is located, that mission is removed from the queue and all other missions following it are moved up one number in the queue.

3. Queue Discipline

There are two types of queue discipline available to the user. The type desired is specified by the input variable QDISC, which may have the following values:

1: First-come first served.

2: Personnel missions have priority.

The use of QDISC = 2 places type 1 and 2 missions ahead of type 3 and 4 missions in the queue. There is no priority relationship between type 1 and 2 missions. Note that QDISC = 2 should not be used when ASNDOC = 2, or vice-versa, since ASNDOC = 2 only allows 5"/38 ships to fire personnel missions. There is no provision in the program for missions which are already in progress (i.e., a ship has been assigned) to be preempted by any other mission. Thus, once a ship is assigned to fire a mission, it is not available for any other mission until that mission is completed.

G. SERVICE TIME

Each time a ship is assigned to fire a mission, subroutine SERVIC is called to calculate the service time for that mission. The arguments of SERVIC are type of ship assigned, target type, target range, mission number, and distance of assigned ship from the firing position. S/R SERVIC calculates the total service time of the mission and amount of ammunition expended during the mission.

1. Total Service Time (SERVC(I))

There are three components of total service time:

a. Travel Time (TRAVEL(I))

Travel time is the time required for the ship to reach the firing position after it has been assigned. It is calculated in one of three ways.

(1) Ship Coming from the Waiting Pattern. If the assigned ship was assigned by virtue of having been the closest available ship of appropriate type at the time the mission was called for, then its travel distance is the distance calculated by the method described in Section III.E.3.

(2) Ship Having Just Completed Another Mission. In this case the travel distance is the distance along the gunline between the two firing positions. This distance is

RUN = IABS (EWTAR(E)-EWTAR(P))

where E is the number of the mission just completed and P is the number of the new mission to which the ship has been assigned.

(3) Ship Having Just Completed Refueling and/or Rearming. A ship is considered to have completed refueling and/or rearming when it returns to a position midway between the northern and southern edges of the waiting pattern and due south of the firing position. Then travel distance is

RUN = WTDIS + NSWAIT/2.

Regardless of which of the above methods is used to calculate travel distance, S/R SERVIC calculates travel time as

TRAVEL(I) = DIS/(SPEED * 33.33)

where DIS is the appropriate travel distance, SPEED is an input variable which specifies the speed (in knots) at which ships proceed to the firing position, and 33.33 is a factor which converts knots (nautical miles/hour) to yards/minute.

b. Setup Time (SETUP(I))

This is the time required for a ship to fix its navigational position and ready its guns after it has reached the firing position. S/R SERVIC calculates setup time as a uniformly distributed random variable between the minimum expected setup time (MINSET) and maximum expected setup time (MAXSET), where MINSET and MAXSET are input variables specified by the user.

c. Firing Time (FIRE(I))

Actual firing time is the time interval between the time the first round is fired and the time the last round is fired. For each mission this is considered to be an exponentially distributed random variable with a mean which is a function of the type of ship firing, the target type, and the target range.

(1) Mean Firing Time Due to Target Range. The portion of the mean firing time which is due to the target range is considered to be a linear function of the target range. This portion is calculated as RANGE(I)/DENOM(J,K), where J is the type ship and K is the target type. The values of DENOM(J,K) are specified by the user for each possible combination of ship type vs. target type. Thus, DENOM is a 4 x 4 matrix.

(2) Mean Firing Time Due to Target Type. This quantity is specified by the user as FIRTIM(J,K) where J is the ship type and K is the target type. Thus, FIRTIM is also a 4 x 4 matrix.

The mean of the exponentially distributed firing time for each mission is calculated as

MU = RANGE(I)/DENOM(J,K) + FIRTIM(J,K).

Therefore, the firing time for each mission is calculated as

FIRE(I) = -MU*ALOG(XRN).

After travel, setup, and firing time have been calculated, total service time is calculated as

SERVC(I) = TRAVEL(I) + SETUP(I) + FIRE(I).

2. Ammunition Expenditure (AMMEXP(I))

S/R SERVIC also calculates the amount of ammunition expended during each mission. The user specifies the minimum (MINAMM(J,K)) and maximum (MAXAMM(J,K)) expected rounds of ammunition expended per minute by ship type J firing against target type K. These values should take into account the average rounds per minute over an entire mission, i.e., the slow rate of fire at the beginning of the mission and the rapid rate of fire after the fire has been spotted onto the target should be averaged. Therefore, MAXAMM(J,K) should normally not be the maximum attainable rate of fire by a type J ship.

The number of rounds of ammunition expended per minute for each mission is calculated as a uniformly distributed random variable between MINAMM(J,K) and MAXAMM(J,K). Therefore the number of rounds of ammunition expended during the I^{th} mission is calculated as

AMMEXP(I) = (MINAMM(J,K)+XRN*(MAXAMM(J,K)-MINAMM(J,K)))*FIRE(I)

where J is the type of ship and K is the type of target.

H. REFUELING AND REARMING

The user has two options available for taking refueling and rearming of ships into account in the problem. The option desired is specified by the input variable REPPOL (Replenishment Policy), which has values defined as follows:

1: Ships do not refuel or rearm.

2: Ships refuel according to a predetermined schedule and rearm when their on-board ammunition level reaches a specified minimum level.

The case in which ships do not rearm or refuel would arise when enough ships are available to replace ships which are required to depart for refueling and/or rearming, thus the departure of the affected ship would not effect the queueing results.

If REPPOL = 2, refueling and rearming is handled in the following ways in the program:

1. Refueling

a. Methods of Establishing a Refueling Schedule

The user establishes a refueling schedule for all ships for the entire duration of the problem. There are two options available for establishing this schedule. The desired option is specified by the input variable REFSKD, which has values defined as follows:

1: The user specifies the exact time of each scheduled refueling for each ship. For each type of ship, a data card is prepared which contains the floating point time (in days from zero problem time to 2 decimal places) that each ship of that type is to depart station for its first scheduled refueling. Similar cards are prepared for the 2nd, 3rd, and up to the 9th scheduled refuelings for ships of each type. These refueling times are the values of the variable XFULSK(I,J,K), where I is the ship number, J is the ship type, and K is the number of the refueling. The total number of rounds of refueling is specified by the input variable FINFUL (must be ≤9). Thus, there must be 4 x FINFUL cards in the refueling schedule data deck. The program converts these scheduled refueling times to minutes from zero problem time and places them on the Event Chain in the proper chronological order.

2: The refueling schedule scheme discussed above is replaced by a simpler (although less flexible) scheme. The entire schedule is specified on one data card. The first five quantities on the card are the floating point times (in days from zero problem time to 2 decimal places) that the first cruiser is to depart for its 1st thru 5th scheduled refueling. These are specified by the input variables XCRFST(I), I = 1 thru 5. The next 5 quantities are the times the first destroyer is to depart for its 1st through 5th scheduled refuelings. These are specified by the input variables XDDFST(I), I = 1 thru 5. The last two numbers are the time interval in minutes at which succeeding cruisers and destroyers follow the first for refueling. These are specified by the input variables CRINT and DDINT. The program then calculates a refueling schedule for the entire duration of the problem using these parameters. There are several rules which must be followed in the preparation of the refueling schedule data cards.

a. For ships which are not present in the problem, the appropriate columns on the data cards should be left blank.

b. If REFSKD = 1, for ships which are present in the problem but are not scheduled to refuel FINFUL times, a large number (99.00 for example) must be inserted in the appropriate columns on the data cards.

c. If REFSKD = 2 and less than five rounds of refueling are to be used, a large number (99.00) must be inserted in the appropriate columns on the data card.

d. If REFSKD = 1 and no ships of a particular type are present in the problem, a blank card must be inserted in the data deck in the appropriate place for each round of refuelings.

Examples

REFSKD = 1: The expected duration of the problem is 10.0 days. NR855 = 2, NR647 = 0, NR554 = 1, NR538 = 2. It is desired that the cruisers refuel on the sixth day and the destroyers refuel on the fifth and ninth days. Then typical values of XFULSK(I,J,K) would be

First Card	Fifth Card
XFULSK(1,1,1) = 5.50	XFULSK(1,1,2) = 99.00
XFULSK(2,1,1) = 5.75	XFULSK(2,1,2) = 99.00
Third Card	**Seventh Card**
XFULSK(1,3,1) = 4.25	XFULSK(1,3,2) = 8.25
Fourth Card	**Eighth Card**
XFULSK(1,4,1) = 4.50	XFULSK(1,4,2) = 8.50
XFULSK(2,4,1) = 4.75	XFULSK(2,4,2) = 8.75

FINFUL = 2 (2 rounds of refueling). Therefore there would be 8 data cards, of which the 2nd and 6th data cards would be blank since NR647 = 0.

REFSKD = 2: For the same situation described above, the following values on one data card would produce the same schedule as above:

XCRFST(1) = 5.50	XDDFST(1) = 4.25
XCRFST(2) thru XCRFST(5) = 99.00	XDDFST(2) = 8.25
CRINT = 360	XDDFST(3) thru XDDFST(5) = 99.00
DDINT = 360	

b. Latest Fueling Time

The program calculates the time of extraction of each patrol from its subarea as INSERT(NR) plus a uniformly distributed random variable between XSHORT(NR) and XLONG(NR). The latest of these extraction times is stored as the variable MAXTRC. In computing the fueling schedule according to user input parameters, no refuelings are placed on the Event Chain which have a scheduled time later than MAXREF = MAXTRC - NOMO, where NOMO is an input variable specified by the user. MAXREF is defined as the latest time that ships will depart for refueling. For example, if it is desired that no ship depart for refueling later than 6 hours before the latest anticipated extraction time, then NOMO = 360.

2. Rearming

The user specifies several input variables which are used to determine when each ship requires rearming. These input variables are defined as follows:

INAMM(S,T): The initial ammunition level (rounds on board) of ship number S of type T.

MINAMM(J,K) and MAXAMM(J,K): Defined in Section III.G.2.

MINLEV(T): The minimum ammunition level to which a ship of type T is allowed to fall before it is required to rearm.

Each time a mission is fired, ammunition expenditure for that mission is calculated by S/R SERVIC as discussed in Section III.G.2. This amount is subtracted from the current ammunition level of the ship which fired the mission, as follows:

$$AMMLEV(S,T) = AMMLEV(S,T) - AMMEXP(I).$$

If AMMLEV(S,T) $\leq$ MINLEV(T), the ship is sent to rearm.

3. Rearming and Refueling Completions

a. Refueling

When an event for which EVTYP(K) = 3 (scheduled refueling) occurs, the status of the scheduled ship is checked.

If the ship is presently firing a mission (STATUS(S,T) = 2) it is placed in a "refuel after mission" status (STATUS(S,T) = 3). If STATUS(S,T) = 1, the ship is sent to refuel immediately. In either case, the time of completion of fueling is calculated as follows:

The user specifies the minimum and maximum expected lengths of time that it should take for a cruiser and a destroyer to refuel. These are the input variables MINFLC, MAXFLC, MINFLD, and MAXFLD. These times should take into account travel time to and from the rendezvous point as well as time alongside the oiler. For example, if it is planned that ships will rendezvous with the oiler at a point 20 miles from the center of the waiting pattern and will proceed to the rendezvous point at a speed of 20 knots, and that a destroyer should require 30 to 60 minutes alongside the oiler, than MINFLD should be 60+30+60 = 150, and MAXFLD should be 60+60+60 = 180.

The time of completion of refueling (COMFUL) is calculated as CLOCK time (the time the ship departed for refueling, either after a mission is completed or at the scheduled refueling time) plus a uniformly distributed random variable between MINFLC and MAXFLC for cruisers, or MINFLD and MAXFLD for destroyers. COMFUL is then placed on the Event Chain.

b. Rearming

Completion of rearming (COMARM) is handled in the same way as COMFUL except that the parameters of the uniform distribution of rearming time are MINARC, MAXARC, MINARD, and MAXARD, specified by the user with the same considerations as the refueling time parameters. When COMARM is calculated, the rearming ship's ammunition level (AMMLEV(S,T)) is set equal to its initial ammunition level (INAMM(S,T)).

c. Combined Refueling/Rearming

When a ship which is scheduled to refuel is off-station for rearming at the time the scheduled refueling occurs, then a refueling time calculated in the manner described above is added to the previously calculated COMARM. From this time, the input variable COMBO is subtracted. COMBO is defined as the amount of time off-station saved by conducting both refueling and rearming in the same evolution. Thus, it should be approximately equal to the time for a one-way trip from the ammunition ship to the waiting pattern plus the time for a one way trip from the waiting pattern to the oiler, minus the time required to travel from the ammunition ship to the oiler. COMBO must not be greater than MINFLD or MINFLC.

The previously calculated COMARM is removed from the Event Chain and the new time of completion of combined refueling/rearming (COMREP) is placed on the Event Chain.

I. OUTPUT DATA

All output of the program is well-formatted to facilitate reading and interpretation. Each type of output is discussed below.

1. Printout of Input Data

A printout of the user-specified values of most of the input variables is produced at the beginning of the output data. Appendix C contains an example of this printout.

2. Mission History

The Mission History is a chronological list of the 12 most significant parameters assigned to each mission during a particular iteration of the problem. There are three options available to the user concerning the Mission History printout. The desired option is specified by the input variable MISHIS, which has values as follows:

1: No Mission History printout desired.

2: Printout Mission History for the first iteration only.

3: Printout Mission History for each iteration.

The time of call for fire and completion of each mission are converted to date-time groups in the Mission History printout. The first 1 or 2 digits are the problem day and the last four digits are the 24-hour clock time.

Appendix D contains an example of the Mission History printout.

3. Statistical Results for Each Iteration

For each iteration, a printout of the pertinent queueing, ship utilization, refueling, rearming, and ammunition expenditure statistics is available. These are the results for that iteration only, they are not cumulative over all iterations up to that point. The user specifies whether printout of iteration statistical results is desired by the input variable ITSTAT, which may have the following values:

1: Printout of iteration statistical results is desired.

2: Printout of statistical results for each iteration is not desired.

Appendix E contains an example of the printout of iteration statistical results.

4. Overall Statistical Results

After all NRIT iterations of the problem have been completed, a printout of the pertinent overall statistical results is produced. This printout includes the mean and the standard deviation of the mean for each quantity except for refueling, rearming, and ammunition expenditure data, for which the mean only is printed out.

In computing the mean and the standard deviation of the mean of the quantities in the overall statistical results, the following formulas are used:

$$\bar{\bar{x}} = \frac{1}{n} \sum_{i=1}^{n} \bar{x}_i$$

$$\sigma_{\bar{\bar{x}}} = \sqrt{\frac{\frac{1}{n-1}\left[\sum_{i=1}^{n} \bar{x}_i^2 - \left(\sum_{i=1}^{n} \bar{x}_i\right)^2/n\right]}{n}}$$

where $\bar{x}_i$ is the result of the i^{th} iteration and n = NRIT.

Using the means and standard deviation from the overall statistical results for NRIT iterations, confidence intervals for the actual value of each output quantity can be calculated using the following formula:

$$\bar{\bar{x}} - \sigma_{\bar{\bar{x}}}\ t^{(n-1)}_{(1-\alpha)/2} \leq \mu \leq x + \sigma_{\bar{\bar{x}}}\ t^{(n-1)}_{(1-\alpha)/2}$$

where $\bar{\bar{x}}$ is the observed mean, $\sigma_{\bar{\bar{x}}}$ is the observed standard deviation of the mean, and $t^{(n-1)}_{(1-\alpha)/2}$ is the value from a table of values of the Student's-t distribution with n-1 degrees of freedom at the $(1-\alpha)/2$ level of significance. α is defined as the probability that the actual value of the quantity lies outside of a confidence interval calculated by the above formula. Therefore $(1-\alpha)$ is the degree of confidence with which statements concerning the actual value of the quantity can be made.

Example:

μ = AVERAGE WAITING TIME PER MISSION

10 iterations of a problem yield $\bar{\bar{x}} = 20.0$ and $\sigma_{\bar{\bar{x}}} = 1.00$. The user desires to be able to predict with 95% confidence the interval in which the actual value of AVERAGE WAITING TIME PER MISSION lies based on these results of 10 iterations. A table of values of the Student's-t distribution shows $t^{9}_{.975} = 2.26$. Therefore, it can be stated with 95% confidence that

$$20.0 - (1.00)(2.26) \leq \mu \leq 20.0 + (1.00)(2.26)$$

or

$$17.74 \leq \text{AVERAGE WAITING TIME PER MISSION} \leq 22.26.$$

Appendix F contains an example of the printout of overall statistical results.

J. INPUT DATA - DATA DECK

This section lists all input variables in the data deck by card and column number(s). For each variable the following information is listed: variable name, subsection of section III in which the variable is described, the FORTRAN variable type, the maximum possible value which can be assigned, and the units of the indicated quantity. All quantities must be right-adjusted within their appropriate columns.

1. First Card: Miscellaneous Problem Definition Variables

Cols	Variable	Reference	Type	Maximum	Units
1-2	NPAREA	B.1	I2	50	Subareas
3	NR855	A.5	I1	9	Ships
4	NR647	A.5	I1	9	Ships
5	NR554	A.5	I1	9	Ships
6	NR538	A.5	I1	9	Ships
7-11	MAX855	D.3	I5	99999	Yards
12-16	MAX647	D.3	I5	99999	Yards
17-21	MAX554	D.3	I5	99999	Yards
22-26	MAX538	D.3	I5	99999	Yards
27-31	MAXNGF	D.3	I5	99999	Yards
32-38	WTNW	B.3	I7	9999999	Yards
39-45	WTNE	B.3	I7	9999999	Yards
46-51	NSWAIT	B.3	I6	999999	Yards
52-57	WTDIS	B.3	I6	999999	Yards
58-59	SPEED	G.1.a	I2	99	Knots
60-61	MINSET	G.1.b	I2	99	Minutes
62-63	MAXSET	G.1.b	I2	99	Minutes
64-67	HHOUR	C.2.a.(1)	I4	1439	Minutes

2. Second Card: Program Control Indicators

Cols	Variable	Reference	Type	Maximum	Units
1	ASNDOC	D.1	I1	2	---
2	QDISC	F.3	I1	2	---
3	REPPOL	H	I1	2	---
4	REFSKD	H.1	I1	2	---
5	FINFUL	H.1	I1	9	Rounds of Refueling
6	MISHIS	I.2	I1	3	---
7	ITSTAT	I.3	I1	2	---
8-10	NRIT	A.7	I3	999	Iterations

3. Next NRAREA Cards: Subarea Information Cards

One card is prepared for each patrol subarea. Cards are placed in the data deck in order of subarea numbers. NR is the subarea number.

Cols	Variable	Reference	Type	Maximum	Units
1-7	NORTH(NR)	B.2	I7	9999999	Yards
8-14	SOUTH(NR)	B.2	I7	9999999	Yards
15-21	EAST(NR)	B.1	I7	9999999	Yards
22-28	WEST(NR)	B.1	I7	9999999	Yards
29-33	XCFF(NR)	C.2.a	F5.1	999.9	Missions
34-38	XSHORT(NR)	C.2.a	F5.1	999.9	Days
39-43	XLONG(NR)	C.2.a	F5.1	999.9	Days
44-49	INSERT(NR)	C.2.a.(1)	I6	999999	Minutes
50-54	XPROB1(NR)	C.2.b.(5)	F5.2	1.00	Probability
55-59	XPROB2(NR)	C.2.b.(5)	F5.2	1.00	Probability
60-64	XPROB3(NR)	C.2.b.(5)	F5.2	1.00	Probability
65-69	XPROB4(NR)	C.2.b.(5)	F5.2	1.00	Probability

4. Next 2 Cards: Parameters of Mean Firing Time

First Card: Mean Firing Time Due to Target Type

Cols	Variable	Reference	Type	Maximum	Units
1-2	FIRTIM(1,1)	G.1.c.(2)	I2	99	Minutes
3-4	FIRTIM(2,1)	"	"	"	"
5-6	FIRTIM(3,1)	"	"	"	"
7-8	FIRTIM(4,1)	"	"	"	"
9-10	FIRTIM(1,2)	"	"	"	"
11-12	FIRTIM(2,2)	"	"	"	"
13-14	FIRTIM(3,2)	"	"	"	"
15-16	FIRTIM(4,2)	"	"	"	"
17-18	FIRTIM(1,3)	"	"	"	"
19-20	FIRTIM(2,3)	"	"	"	"
21-22	FIRTIM(3,3)	"	"	"	"
23-24	FIRTIM(4,3)	"	"	"	"
25-26	FIRTIM(1,4)	"	"	"	"
27-28	FIRTIM(2,4)	"	"	"	"
29-30	FIRTIM(3,4)	"	"	"	"
31-32	FIRTIM(4,4)	"	"	"	"

Second Card: Denominator of Range Component

Cols	Variable	Reference	Type	Maximum	Units
1-5	DENOM(1,1)	G.1.c.(1)	I5	99999	Yards/Minute
6-10	DENOM(2,1)	"	"	"	"
.	.				
.	.				
	(Same order of subscripts as FIRTIM)				
.	.				
.	.				
76-80	DENOM(4,4)	"	"	"	"

(IF REPPOL = 1, skip to section III.J.7)

5. Refueling Data

a. First Card: Miscellaneous

Cols	Variable	Reference	Type	Maximum	Units
1-4	NOMO	H.1.b	I4	9999	Minutes
5-8	COMBO	H.3.c	I4	9999	Minutes

(IF REFSKD = 2, skip to section III.J.5.c)

b. Next 4 x FINFUL Cards: User-Input Refueling Schedule

Cols	Variable	Reference	Type	Maximum	Units
First Card					
1-7	XFULSK(1,1,1)	H.1	F7.2	9999.99	Days
8-14	XFULSK(2,1,1)	"	"	"	"
.	.				
.	.				
.	.				
57-63	XFULSK(9,1,1)	"	"	"	"
Second Card					
1-7	XFULSK(1,2,1)	"	"	"	"
8-14	XFULSK(2,2,1)	"	"	"	"
.	.				
.	.				
.	.				
57-63	XFULSK(9,2,1)	"	"	"	"
Third Card					
1-7	XFULSK(1,3,1)	"	"	"	"
8-14	XFULSK(2,3,1)	"	"	"	"
.	.				
.	.				
.	.				
57-63	XFULSK(9,3,1)	"	"	"	"
Fourth Card					
1-7	XFULSK(1,4,1)	"	"	"	"
8-14	XFULSK(2,4,1)	"	"	"	"
.	.				
.	.				
.	.				
57-63	XFULSK(9,4,1)	"	"	"	"

Next 4 Cards

Same as first four cards except that third subscript is 2.

Continue in the same manner until there are FINFUL sets of 4 cards each. There must be 4 x FINFUL cards in the user-input refueling schedule section of the data deck.

(Skip to section III.J.5.d)

c. Next Card: Parameters of Computer-Calculated Refueling Schedule

Cols	Variable	Reference	Type	Maximum	Units
1-6	XCRFST(1)	H.1.a	F6.2	999.99	Days
7-12	XCRFST(2)	"	"	"	"
13-18	XCRFST(3)	"	"	"	"
19-24	XCRFST(4)	"	"	"	"
25-30	XCRFST(5)	"	"	"	"
31-36	XDDFST(1)	"	"	"	"
37-42	XDDFST(2)	"	"	"	"
43-48	XDDFST(3)	"	"	"	"
49-54	XDDFST(4)	"	"	"	"
55-60	XDDFST(5)	"	"	"	"
61-65	CRINT	"	I5	99999	Minutes
66-70	DDINT	"	I5	99999	Minutes

d. Next Card: Minimum and Maximum Refueling Off-Station Times

1-5	MINFLC	H.3.a	I5	99999	Minutes
6-10	MAXFLC	"	"	"	"
11-15	MINFLD	"	"	"	"
16-20	MAXFLD	"	"	"	"

6. Rearming Data

a. First Card: Minimum Allowed Ammunition Levels and Minimum and Maximum Rearming Off-Station Times

Cols	Variable	Reference	Type	Maximum	Units
1-6	MINLEV(1)	H.2	I6	999999	Rounds
7-12	MINLEV(2)	"	"	"	"
13-18	MINLEV(3)	"	"	"	"
19-24	MINLEV(4)	"	"	"	"
25-29	MINARC	H.3.b	I5	99999	Minutes
30-34	MAXARC	"	"	"	"
35-39	MINARD	"	"	"	"
40-44	MAXARD	"	"	"	"

b. Next 4 Cards: Initial Ammunition Levels

First Card

1-7	INAMM(1,1)	H.2	I7	9999999	Rounds
8-14	INAMM(2,1)	"	"	"	"
.	.				
.	.				
.	.				
57-63	INAMM(9,1)	"	"	"	"

Second Card

1-7	INAMM(1,2)	"	"	"	"
8-14	INAMM(2,2)	"	"	"	"
.	.				
.	.				
.	.				
57-63	INAMM(9,2)	"	"	"	"

Third Card

1-7	INAMM(1,3)	"	"	"	"
8-14	INAMM(2,3)	"	"	"	"
.	.				
.	.				
.	.				
57-63	INAMM(9,3)	"	"	"	"

Fourth Card

1-7	INAMM(1,4)	H.2	I7	9999999	Rounds
8-14	INAMM(2,4)	"	"	"	"
.	.				
.	.				
.	.				
57-63	INAMM(9,4)	"	"	"	"

7. Next 2 Cards: Ammunition Expenditures Per Minute

Cols	Variable	Reference	Type	Maximum	Units
First Card					
1-4	MINAMM(1,1)	G.2	I4	9999	Rounds/Minute
5-8	MINAMM(2,1)	"	"	"	"
.	.				
.	.				
	(Same order of subscripts as FIRTIM)				
.	.				
.	.				
61-64	MINAMM(4,4)	"	"	"	"
Second Card					
1-4	MAXAMM(1,1)	"	"	"	"
5-8	MAXAMM(2,1)	"	"	"	"
.	.				
.	.				
	(Same order of subscripts as FIRTIM)				
.	.				
.	.				
61-64	MAXAMM(4,4)	"	"	"	"

8. Last Card: Random Number Generator Initializers

This card contains a string of 70 random digits in columns 1-70, with the requirement that every fifth column contains an odd number.

K. COMPUTER STORAGE AND TIME REQUIREMENTS

The program runs on an IBM-360/67 at the W. R. Church Computer Center at the U. S. Naval Postgraduate School. For other systems, the storage and time requirements may differ from those stated below.

1. Computer Storage

The amount of core area required is dependent on the amount of array storage set aside for array variables, which of course depends on the estimated size of the problem to be simulated. The program as presented in Appendix B allows up to 2300 events and 1000 missions to be generated during each iteration of the problem. Thus the 19 parameters associated with each mission all have dimension size 1000 and the 4 parameters associated with each event all have dimension size 2300. With these array sizes, the program requires approximately 195K bytes of execution core area.

2. Computer Central Processing Unit Time

The program requires approximately 1 minute and 25 seconds of CPU time for the compile and link steps. CPU time required in execution is primarily dependent on the number of missions generated and the number of iterations performed. The amount of execution time can be calculated approximately as 1/200 seconds per mission per iteration. The expected number of missions per iteration is approximately $\sum$ XCFF(NR).

Therefore, if the expected number of missions per iteration for a problem is 500 and 10 iterations are performed (NRIT = 10), then

$$\text{Execution Time} \cong 500(1/200)(10) = 25 \text{ seconds.}$$

IV. VERIFICATION AND VALIDATION OF THE MODEL

A. VERIFICATION

The fact that logic flow in the program is as intended and that output statistics accurately describe the situation being simulated has been verified in several ways. These are discussed below.

1. Verification of Intermediate Calculations and Data Flow

During the formulation of the program and numerous debugging runs, results of calculations and other pertinent data at various points in the program were printed out to determine their correctness. When the program was considered finally debugged, such checks were performed at all points in the program at which calculations were performed or significant data points referenced. The results of these checks were carefully examined, and all values were determined to be correct.

2. Tracing

Logic flow through all possible branches of the program has been carefully traced and determined to be as intended.

3. Extreme Value Problems

When the program was considered finally debugged, several problems were formulated using extreme foreseeable maximum and minimum values of input parameters. In each case, the program successfully ran to completion with statistical results reflecting the extreme values.

4. Verification of Exponential Distribution

To verify that mission interarrival times are actually produced according to the exponential distribution, a Kolmogorov-Smirnoff test for goodness-of-fit was performed on the interarrival times in a subarea picked at random in a trial run of the program. The subarea picked was subarea 11. The following input data was used for subarea 11 in the trial run:

XCFF(11) = 35.0 missions

XSHORT(11) = 6.5 days

XLONG(11) = 7.5 days

Thus,

XDURAT(11) = 7.0 days

XCALRT(11) = .00347 missions/minute.

The continuous curve in Figure 3 is a plot of the CDF of an exponential distribution with rate = .00347. The step function in Figure 3 is the sample CDF of the 23 mission interarrival times generated for subarea 11 in the trial run.

The Kolmogorov-Smirnoff test [pp. 238-240, Ref. 5] consists of observing the absolute difference between the value of the sample CDF and the value of the hypothesized CDF at all points in the sample. The test statistic is

$$D_n = \max_n \{ \mid F(x) - F_n(x) \mid \}$$

where F(x) is the value of the hypothesized CDF at x and $F_n(x)$ is the observed value of the sample CDF at x for a sample of size n.

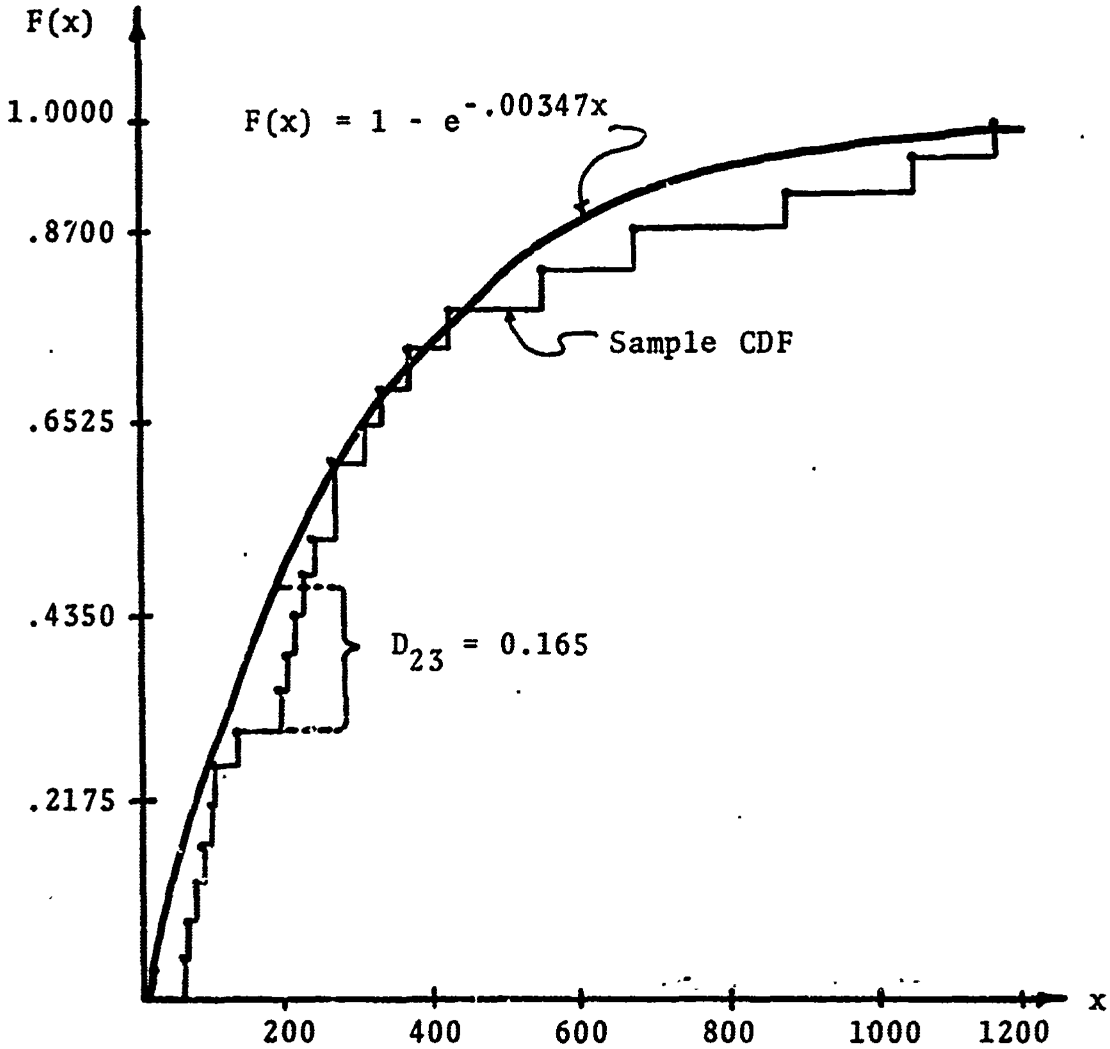


Figure 3. Kolmogorov-Smirnoff Test for Goodness-of-Fit of Mission Interarrival Times to the Exponential Distribution.

Inspection of Figure 3 yields D_{23} = .165. Table VI in Reference 5 shows that $D_{23} \leq .276$ is acceptable with 95% confidence. Therefore the sample of interarrival times in subarea 11 successfully passes the Kolmogorov-Smirnoff test for goodness-of-fit for the exponential distribution. From this result, it was assumed that all interarrival times and mission firing times fit an exponential distribution, since the same method of generating exponentially distributed random variables was used in each case.

5. <u>Comparison with GPSS Model</u>

A short program in the General Purpose Simulation System (GPSS) was written to simulate the system described herein in a very basic mode, which was easily adaptable to GPSS. The program described herein was run using input values which placed it in exactly the same mode as the GPSS program. The queueing results of each were then compared and found to be in very close agreement.

6. <u>Verification of Relationships Between Output Statistics</u>

By investigating the mathematical relationships between various output statistics, it was verified that the calculations which produce the output values are properly performed. An example of an investigation of such a relationship is discussed below.

OVERALL SHIP UTILIZATION: If refueling and rearming are not used in the problem, overall ship utilization should equal

$$\frac{\text{Total Missions x Average Service Time Per Mission}}{\text{Number of Ships x Total Problem Time}}$$

For a trial run of the program in which refueling and rearming were not used, the following results were obtained:

NR855 = NR647 = NR538 = 1

NR554 = 0

TOTAL NUMBER OF MISSIONS FIRED = 385

AVERAGE SERVICE TIME PER MISSION = 43.0 minutes

TOTAL PROBLEM TIME = 8 days, 15 hours, 54 minutes

OVERALL SHIP UTILIZATION = 0.44.

Using these figures in the formula stated above yields:

$$\text{Overall Ship Utilization} = \frac{385 \times 43.0}{3 \times (8 \times 1440 + 15 \times 60 + 54)} = .442.$$

Since overall ship utilization is not calculated using the above formula in the program, but rather by accumulating an overall sum of minutes of utilization for each ship, this result lends further verification to both logic flow and accuracy of all of the above listed output statistics. By methods similar to the above, calculations of other related output statistics were also verified.

7. Sensitivity Testing

As a final method of verification, the sensitivity of the model to changes in input parameters was tested. An example of such tests is discussed below.

WTDIS: A trial run of the program was made using WTDIS = 4000. The output statistics for this problem yielded:

AVERAGE TRAVEL TIME = 16.5 minutes

AVERAGE WAITING TIME (ALL MISSIONS) = 8.3 minutes

PERCENT OF MISSIONS REQUIRED TO WAIT = 26.5%.

The same problem was then run using WTDIS = 8000, all other input values remaining unchanged. It was expected that each of these output statistics would increase by amounts estimated as follows:

a. Average travel time should increase by approximately

$$.70 \left(\frac{4000}{20 \times 33.3} \right) = 4.2 \text{ minutes}$$

since each ship coming from the waiting pattern would have an additional 4000 yards to travel at a speed of 20 knots, and approximately 70% of the missions were fired by ships coming from the waiting pattern.

b. Average waiting time (all missions) and percent of missions required to wait should increase very slightly due to the small increase in average travel time.

The results of the trial run using WTDIS = 8000 were as follows:

AVERAGE TRAVEL TIME = 20.4 minutes

AVERAGE WAITING TIME (ALL MISSIONS) = 8.5 minutes

PERCENT OF MISSIONS REQUIRED TO WAIT = 27.2

These results are very close to those expected, further verifying logic flow and program results.

B. VALIDATION

The simulation cannot be considered validated since it is obviously infeasible to actually physically conduct a problem for experimental purposes within the scope of this thesis, and no experimental data of similar exercises is available. The design of the model is primarily based on personal experience in NGFS both from aboard ship and as a spotter ashore, and the results obtained by the simulation model appear to be valid within the limits of that experience.

V. PARTIAL STDF FEASIBILITY STUDY

With the computer simulation model finalized and fully tested, a partial study of the feasibility of the STDF concept was undertaken. This study focused only upon the queueing aspects of providing NGFS from the STDF to SIAF's ashore.

A. OBJECTIVE OF THE STUDY

The overall objective of the study can be generally stated as follows:

> "Determine the optimum number and mix of NGFS ships required to adequately support SIAF's in an insurgent-contested area."

Before proceeding further, the term "adequate" support must be defined. Since the model does not consider results of missions fired, adequate support cannot be defined in terms of results achieved. Rather, the definition must be in terms of the queueing aspects of NGFS.

1. Decision Criteria

Two arbitrary decision criteria were established in order to define "adequate" support. These criteria are based solely on personal experience and cannot be considered authoritative. The decision criteria are:

a. The average waiting time per mission should be less than 10 minutes. Spotting teams ashore become quite anxious and their position becomes increasingly tenuous as the length of time between their call for fire and notification that a ship is on the way increases. Ten minutes seems like a reasonable upper bound on the length of time that a patrol should have to expect to wait.

b. Overall ship utilization should be at least 50%. Paucity of ships to assign to a particular operation dictates a requirement such as this, and is the basis of the need for a feasibility study of the queueing aspects of NGFS of SIAF's.

2. Objective Function

Having established the two decision criteria to define "adequate" support, the objective of the study becomes:

"Determine the minimum number (and mix) of NGFS ships required to satisfy the decision criteria."

In terms of the variables and the output statistics in the computer model, the objective can be stated as:

Minimize: NR855 + NR647 + NR554 + NR538

Subject to: AVERAGE WAITING TIME (ALL MISSIONS) $\leq$ 10.0

OVERALL SHIP UTILIZATION $\geq$ 0.50.

3. Optimization Technique

The optimization technique used can be described generally as a 3-step procedure. These steps are:

a. Hypothesize a typical STDF/SIAF situation.

b. Exercise the simulation model, varying the number of ships of each type which are present.

c. Inspect the results of the simulation exercise to determine the minimum number (and mix) of ships which best satisfies the decision criteria.

B. HYPOTHESIZED SITUATION - SCENARIO

In order to exercise the computer simulation, a scenario was developed which seems to describe a typical situation as envisioned under the STDF/SIAF concept.

1. General Situation

A small country, allied with the U.S., is under imminent threat of insurgent takeover. For the past several months, there have been numerous reports of infiltration into the country and tensions have increased with the country's unfriendly neighbor to the southwest. During the past two weeks there have been terrorist attacks in the small fishing villages located along the banks of a river which divides the country roughly in half. The capitol city is located at the mouth of this river. The government now believes that the infiltrators are an insurgent force from the unfriendly neighboring country, and that the insurgents are building up for an attack on the capitol city in an attempt to unseat the present government. The allied country has requested emergency military assistance from the U.S. to suppress the insurgent force.

2. Enemy Situation

The recent terrorist attacks and other reports indicate that the bulk of the enemy force is dispersed along the banks of the river in small guerilla groups. However, since there have been no sightings or use of heavy artillery or other significantly large military equipment near the river, it is believed that some of the enemy force is engaged in transporting heavy equipment to strategic locations to the west of the capitol city. The most likely routes for movement of such equipment are through the sparsely populated mountainous regions in the southwest and northwest parts of the country. There are estimated to be between 7500 and 10000 insurgents within the country at the present time.

3. Friendly Situation

The U.S. has agreed to send elements of the STDF to assist in suppressing the insurgent force. However, the U.S. has made it clear that this military assistance is on an emergency basis only, and will be provided for a period of seven days only. The STDF commander has received specific orders to place only a minimum number of men ashore, and that patrols placed ashore are not to actually engage in combat except in self-defense.

a. NGFS/SIAF Detachment

The STDF commander detached the following ships from the STDF to provide the emergency assistance requested:

1 LHA (with one Marine Expeditionary Unit embarked)

1 AOE

X Cruisers and Destroyers

b. Area of Operations

(1) Objective Area. The objective area is defined as the area surrounding the capitol city, 10 miles north

and south of the river, and including up to the peaks of the mountain ranges in the northwest and southwest. The objective area is approximately 20 miles wide and 10 miles deep (inland from the coast).

(2) Patrol Subareas. Based on expected densities of enemy targets and terrain features, the objective area has been divided into 34 SIAF patrol subareas. Patrols will be inserted into these subareas by helicopter beginning at 0500 (H-hour) on the first day. Order and time of patrol insertion will be randomly picked. All patrols will have been inserted no later than 2100 on the first day.

(3) Waiting Pattern. When not assigned to fire a mission, ships will operate within a 10 mile wide area 4-6 miles offshore and centered on the center of the objective area since the heaviest target densities are expected to be near the center of the objective area.

c. Firing Doctrine

In this situation, the U.S. is very much concerned that its troops ashore not engage in combat unless absolutely necessary. Thus it is desired that all calls for fire from SIAF patrols be answered as rapidly as possible by any ship available, and that personnel targets be fired at before material targets if both occur simultaneously.

d. Refueling and Rearming

(1) Location of AOE. The assigned AOE will remain approximately 15 miles offshore to accomplish refueling and rearming. Thus, a one-way trip from the waiting pattern to the AOE at a speed of 20 knots should require approximately 30 minutes.

(2) Refueling Schedules. Since it is anticipated that the operation will last approximately one week, no ship should require refueling more than once. Destroyers are scheduled to refuel beginning at 1100 on the fifth day, with other destroyers following the first at four-hour intervals. Destroyers may also refuel beginning at 1100 on the ninth day if the operation lasts that long. Cruisers are scheduled to refuel beginning at 1100 on the sixth day, with other cruisers following the first at four-hour intervals. It is anticipated that destroyers should require 60 to 90 minutes alongside the AOE during each refueling, while cruisers should require 90 to 120 minutes. As the operation progresses and the time of withdrawal of all patrols from the objective area becomes reasonably firm, no ship will depart station for refueling within 12 hours of this anticipated time of total withdrawal.

(3) Initial and Minimum Ammo Levels. Prior to arrival at the area of operations, all NGFS ships have topped off their onboard ammunition levels. The STDF commander has prescribed minimum allowable ammunition levels for each type of ship. These ammunition levels are as follows:

Type Ship	Initial	Minimum
8"/55	8000	1000
6"/47	10000	1000
5"/54	12000	2000
5"/38	6000	1000

It is anticipated that destroyers should require 2 to 3 hours alongside the AOE to rearm, while cruisers should require 3 to 4 hours.

C. HYPOTHESIZED SITUATION - INPUT VARIABLES

Having hypothesized what appears to be a typical STDF/ SIAF situation, the next step was to translate the scenario into values of input variables in order to exercise the computer simulation. Appendix C is the printout of input data used in the hypothesized problem, for a run in which NR855 = NR647 = NR554 = 1 and NR538 = 0.

1. Zero Problem Time

Zero problem time is 0500 on the first day of the operation. Thus, HHOUR = 300. All insertion times are in minutes after 0500, i.e., INSERT(2) = 140 indicates a SIAF patrol will be inserted into subarea 2 at 0720 on the first day.

2. Problem Area Map

Figure 4 is a map of the problem area translated into the coordinate system described in Section III.B. Subarea boundaries used are not necessarily exactly as they would be in the actual operation, i.e., the river would probably be the boundary of patrol subareas on either side of it. The following input information is shown on the map for each subarea:

NR	XCFF(NR)
	XPROB1(NR) XPROB2(NR) XPROB3(NR)
INSERT(NR)	XPROB4(NR)

The values used for expected number of calls for fire and target type probabilities are based on the expected locations, density, and type of enemy targets as indicated

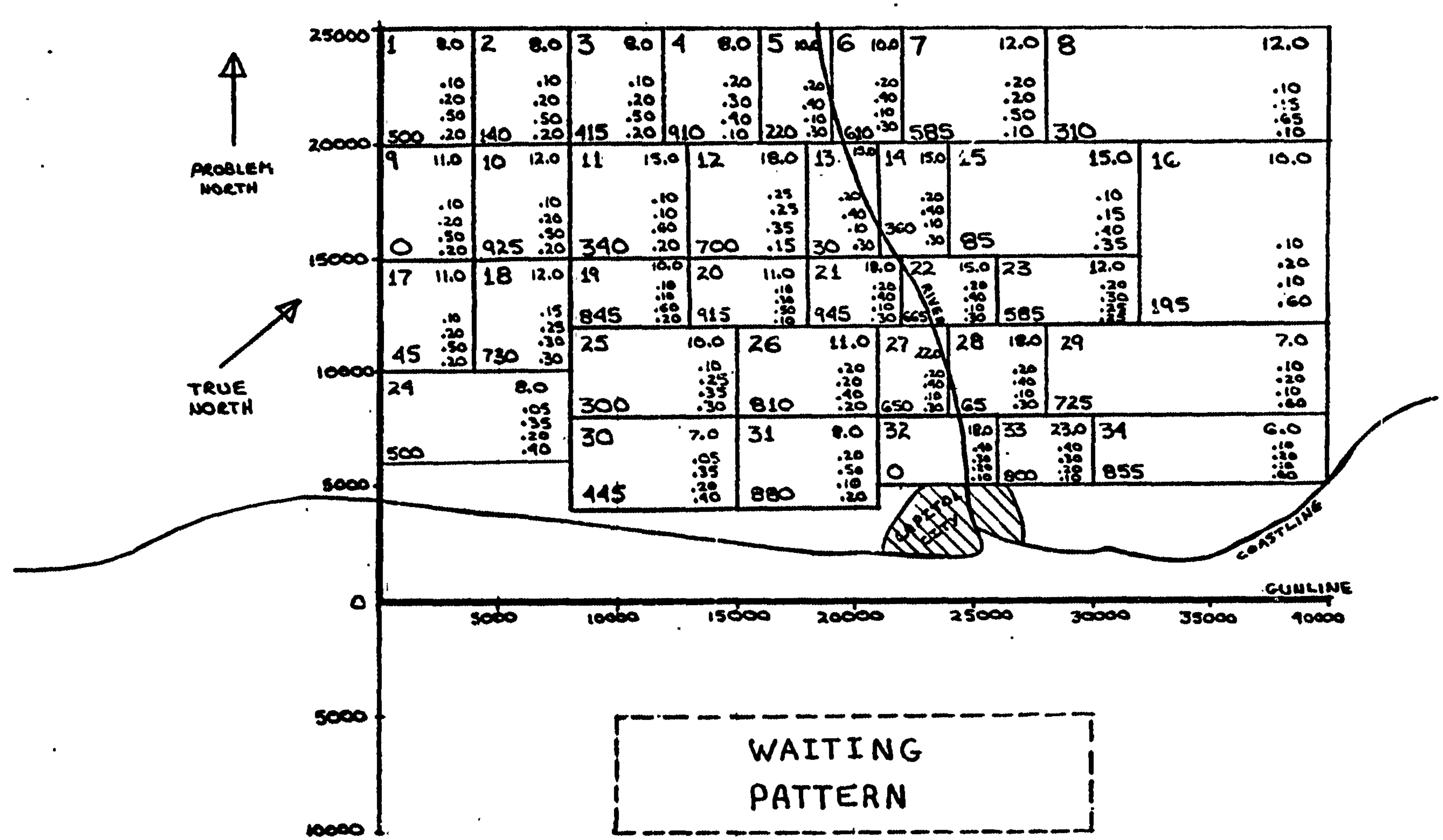


Figure 4. Problem Area Map for STDF Feasibility Study.

in Section V.B.2. XCFF and XPROB1 + XPROB2 are high near the river, and XPROB2 > XPROB1 since it is believed that the insurgent force operates primarily in small guerilla groups. XPROB3 + XPROB4 is high in the mountainous areas to the southwest and northwest, indicating suspected movement of supplies through those areas, with XPROB3 > XPROB4 indicating primarily heavy equipment being moved.

3. Expected Patrol Durations

The maximum and minimum patrol durations were chosen such that the expected time of extraction of each patrol should be approximately 7 days after zero problem time. However, patrol duration parameters are given a wider range of values in the areas of heavy density of enemy personnel. This reflects a higher probability of early extraction due to SIAF personnel casualties.

4. Assignment Doctrine and Queue Discipline

The discussion in Section V.B.3.c implies that "any ship with guns of adequate range may fire" any mission (ASNDOC = 1), and "personnel missions have priority" in the queue (QDISC = 2).

5. Refueling Schedule

The refueling schedule as discussed in Section V.B. 3.d translates into the following values of refueling schedule variables:

REPPOL = 2

REFSKD = 1 (Computer calculated schedule used)

COMBO = 60 (Time for round trip between AOE and waiting pattern is one hour)

NOMO = 720 (No more refuelings within 12 hours of latest extraction time)

XCRFST(1) = 5.25 (5 days, 6 hours after zero problem time is 1100 on 6th day)

XCRFST(2) thru XCRFST(5) = 99.00

XDDFST(1) = 4.25

XDDFST(2) = 8.25

XDDFST(3) thru XDDFST(5) = 99.00

CRINT = 240

DDINT = 240

Other values of refueling and rearming parameters are translated as indicated in Appendix C.

6. Firing Time Parameters

The components of mean firing time as indicated in Appendix C were determined as follows:

a. Denominator of Range Factor

The range to the target generally has less effect on the accuracy of 8"/55 and 6"/47 shells than 5" shells since they are larger and designed for longer ranges.

b. Mean Firing Time Due to Target Type

A 5"/54 gun is considerably more effective against personnel targets and should require considerably less time to fire a personnel target mission due to its rapid rate of fire. 8"/55 and 6"/47 guns require less time against material targets due to their high explosive power, while a 5"/54 gun requires less time than a 5"/38 due to its rapid rate of fire.

D. INVESTIGATION OF VARIOUS NUMBERS AND MIXES OF SHIPS PRESENT

1. Two Ships

Rough calculations based on expected number of missions, expected service time, and expected problem duration indicate that it is very unlikely that any combination of two ships would be able to provide adequate support. These rough calculations are as follows:

$$\sum_{NR=1}^{34} XCFF(NR) = 414.0$$

Expected total service time per mission ≅ 45 minutes

Expected problem duration ≅ 7 days

414 missions x 3/4 hours/mission ≅ 310 ship hours required

Two ships x 7 days x 24 hours/day = 336 ship hours available.

The variability of mission interarrival times, mission firing times, and travel distances, and the requirements for refueling and rearming would most likely cause an unacceptable queueing situation to develop. Therefore, combinations of two ships were not investigated initially.

2. Three Ships

It is not at all apparent from rough calculations whether or not three ships would be able to adequately support the hypothesized operation. Herein lies the basic justification for the use of simulation, since simulation accounts for the variability in problem parameters and produces an average (expected) result on which to base decisions.

To investigate the queueing results for three ships present, the problem was run 16 times, representing all possible combinations of 0 to three ships of each type which add to 3, with the requirement that at least one 8"/55 ship or one 5"/54 ship be present, since the northern extremity of the objective area is 25000 yards from the gunline. Ten iterations per run (NRIT = 10) were used to determine averaged results and standard deviations. Table I, on the next page, presents the two decision criteria output statistics for each of the 16 combinations of ships. Figures in the table are the upper and lower limits of a 95% confidence interval. These limits were calculated using the equation

$$\bar{\bar{x}} - 2.26\,\sigma_{\bar{\bar{x}}} \le \mu \le \bar{\bar{x}} + 2.26\,\sigma_{\bar{\bar{x}}}$$

which was derived as discussed in Section III.I.4.

Inspection of the figures in Table I shows that regardless of the mix of ships, overall ship utilization is approximately 50% when three ships are present. From this observation it can be readily deduced that utilization when four ships are present would be considerably less (probably about 35%) while utilization when only two ships are present would be greater (probably about 65%). Based on this conclusion, the simulation was exercised for the seven possible combinations of two ships to see if any combination would yield a satisfactory average waiting time. The results of these seven runs are presented in Table II, on the next page.

TABLE I. Decision Criteria Output Statistics for Combinations of Three Ships

NR855	NR647	NR554	NR538	AVG WAITING TIME MIN	AVG WAITING TIME MAX	OVERALL SHIP UTILIZATION MIN	OVERALL SHIP UTILIZATION MAX
0	0	1	2	24.0	35.0	.482	.528
0	0	2	1	7.0	10.2	.484	.510
0	0	3	0	3.7	5.3	.447	.485
0	1	1	1	8.6	13.4	.470	.522
0	1	2	0	4.0	6.2	.434	.494
0	2	1	0	5.6	7.8	.477	.493
1	0	0	2	30.5	38.1	.487	.539
1	0	1	1	7.6	10.2	.476	.516
1	0	2	0	3.6	6.6	.460	.508
1	1	0	1	7.8	11.2	.478	.524
1	1	1	0	3.7	5.7	.459	.481
1	2	0	0	6.4	8.0	.475	.507
2	0	0	1	8.5	11.1	.494	.526
2	0	1	0	4.6	8.4	.478	.518
2	1	0	0	4.7	7.3	.476	.522
3	0	0	0	4.5	9.9	.468	.508

TABLE II. Decision Criteria Output Statistics for Combinations of Two Ships

NR855	NR647	NR554	NR538	AVG WAITING TIME MIN	AVG WAITING TIME MAX	OVERALL SHIP UTILIZATION MIN	OVERALL SHIP UTILIZATION MAX
0	0	1	1	48.8	73.4	.687	.743
0	0	2	0	26.0	41.6	.676	.742
0	1	1	0	29.8	42.8	.679	.715
1	0	0	1	65.5	85.9	.719	.767
1	0	1	0	25.6	44.4	.666	.732
1	1	0	0	33.4	45.8	.674	.743
2	0	0	0	33.1	46.9	.685	.751

At this point in the analysis, it was observed that no combination of ships present would simultaneously satisfy the two decision criteria within the limits of a 95% confidence interval. When three ships are present, there is no combination for which it can be said with 95% confidence that OVERALL SHIP UTILIZATION $\geq$ .50, while there is no combination of two ships for which it can be said with 95% confidence that AVERAGE WAITING TIME $\leq$ 10.0 minutes. Thus, one of the two decision criteria had to be relaxed. Inspection of Tables I and II made it readily obvious that the ship utilization criteria was the logical criteria to relax. Thus, the decision criteria was changed to OVERALL SHIP UTILIZATION $\geq$ .43.

With these revised decision criteria, the following nine combinations of three ships satisfy both criteria simultaneously:

NR855	NR647	NR554	NR538
0	0	3	0
0	1	2	0
0	2	1	0
1	0	2	0
1	1	1	0
1	2	0	0
2	0	1	0
2	1	0	0
3	0	0	0

The striking characteristic of these nine combinations is that NR538 = 0 in all of them and they are the only nine combinations in which NR538 = 0. This is obviously because of the short range of the 5"/38 gun, which limits its usability when the objective area is more than 7 miles deep.

In an attempt to further distinguish between these nine combinations of three ships, two other output statistics were investigated. These were MAXIMUM WAITING TIME and PERCENT OF MISSIONS REQUIRED TO WAIT. Table III on the next page presents these statistics for the nine combinations of ships under consideration.

Inspection of Table III indicates that two combinations are considerably less desirable than the others. These are:

NR855	NR647	NR554
0	2	1
1	2	0

The striking characteristic of these combinations is that NR647 = 2 in each of them, and they are the only two combinations of the original 16 in which NR647 = 2.

E. CONCLUSION OF THE STUDY

Based on the foregoing analysis of the output statistics, the following conclusion was reached:

"For a situation such as described herein, any combination of three NGFS ships of which none are 5"/38 ships and less than two are 6"/47 ships is optimal in terms of providing adequate support to SIAF's ashore in an insurgent-contested area."

Table III. MAXIMUM WAITING TIME and PERCENT REQUIRED TO WAIT Statistics for the Nine Best Combinations of Three Ships

NR855	NR647	NR554	MAX WAITING TIME MIN	MAX WAITING TIME MAX	PERCENT REQUIRED TO WAIT MIN	PERCENT REQUIRED TO WAIT MAX
0	0	3	69	141	15.5	32.2
0	1	2	75	169	13.6	36.6
0	2	1	183	251	21.8	31.8
1	0	2	55	123	13.7	39.7
1	1	1	71	111	13.8	34.8
1	2	0	184	342	21.6	33.8
2	0	1	80	220	18.3	37.7
2	1	0	88	174	18.2	37.2
3	0	0	110	254	11.7	41.7

In terms of STDF feasibility, this can be interpreted to mean:

"If three NGFS ships, of which none are 5"/38 ships and less than two are 6"/47 ships, are available for inclusion in the STDF, then the STDF concept is feasible in terms of providing NGFS to SIAF's ashore in a situation such as described herein."

It must be emphasized that these conclusions only apply to the hypothesized situation. The sensitivity of the conclusions to changes in input parameters has not been tested as would certainly be necessary in a detailed feasibility study. It is not considered within the scope of this thesis to undertake such an extensive study. Rather, it is considered that the objectives stated in Section I.C have been met at this point.

VI. CONCLUSIONS

It is recognized that there are several ways in which the model presented in this paper is capable of refinement and extension in order to more accurately simulate realistic SIAF support situations and be more useful in investigating the overall feasibility of the STDF concept. Although such refinement and extensions were not considered to be within the scope of this thesis, some of them are pointed out in this section for possible future consideration by users of the model.

A. REFINEMENT OF THE MODEL

1. Travel Distance Calculations

The calculations of travel distances on which ship assignments are based can be made more realistic by developing a dynamic scheme of keeping track of actual positions of unassigned ships throughout the run of the model.

2. Ship Assignment Doctrines

Ship assignment doctrines other than the two used in this model can be devised to simulate a wider range of realistic options available to the STDF commander in assigning ships to missions.

3. Queue Discipline

A preempt option for "urgent" missions can be introduced to add realism to the model.

4. Refueling and Rearming Off-Station Times

The amount of time spent by each ship off-station for rearming and/or refueling can be made more realistic by developing a method of simulating movement of oilers and ammunition ships throughout the problem.

5. SIAF Patrol Movements

The model can be made more realistic by developing a dynamic scheme of simulating movement of SIAF patrols within their assigned subareas. Such a scheme could possibly be the linking of this model with the TRW SIAF model in some way.

6. Distributions of Variable Quantities

All of the distributions of variable quantities used in the model are based primarily on personal experience in Naval operations. It is possible that some of the distributions do not reflect realistic situations as accurately as some other distribution might. Refinement of the model should include an investigation of historical or experimental data to determine the actual distributions of the variable quantities. For example, data concerning actual mission firing times should be analyzed to determine if firing times actually conform to the exponential distribution or to some other probability distribution.

B. EXTENSIONS OF THE MODEL

1. Inclusion of Air Strikes

The model can be extended to simulate air strikes by helicopters or fixed-wing aircraft originating from carriers assigned to the STDF when targets could be more effectively encountered by air strikes or are beyond the maximum range of Naval gunfire.

2. Inclusion of Battleships

Although there are no battleships in commission at the present time, the possibility that battleships could be brought back into use in the future, as was the case of the NEW JERSEY in the Vietnam War, indicates the desirability of including battleships in the model. However, if no ships of a particular type were present in a particular problem, the model in its present state could be used to simulate the presence of battleships by assigning battleship parameters to the input variables normally used for ships of the type not present. This might require some modification to the ship assignment doctrine.

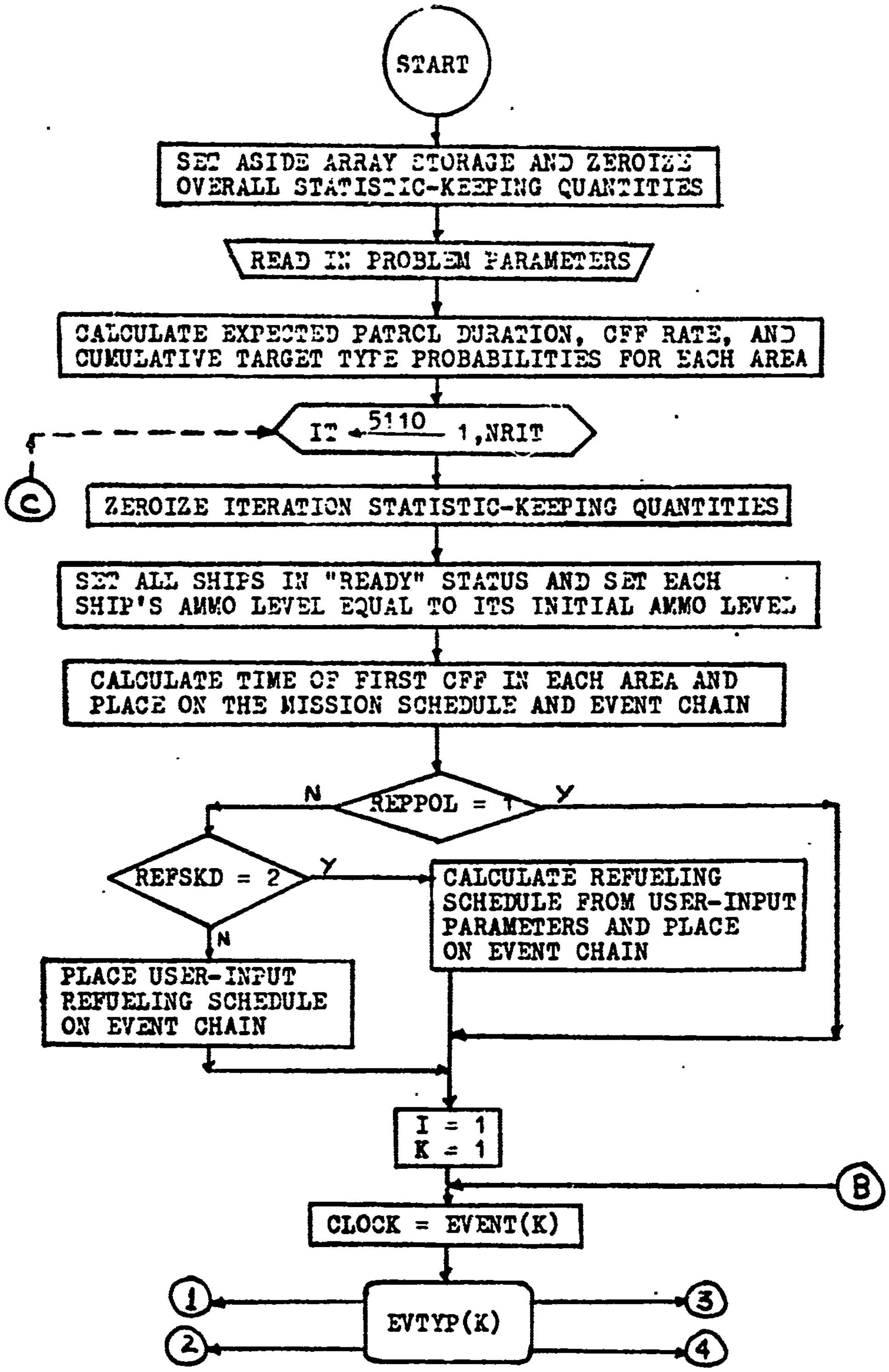
3. Multiple Patrols in a Subarea

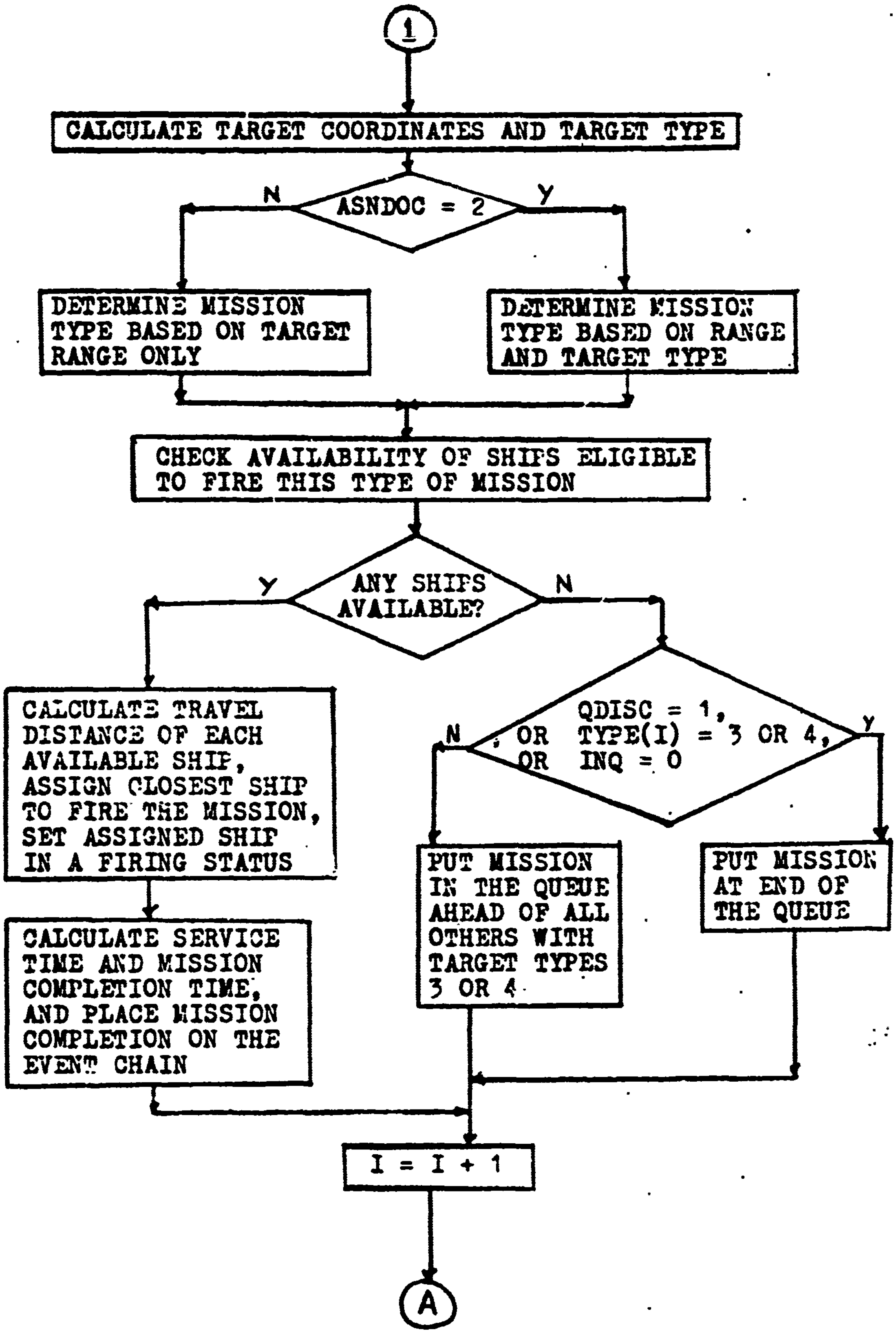
The model could be extended to include the option of inserting a second patrol into a subarea when the first patrol is extracted, and so on.

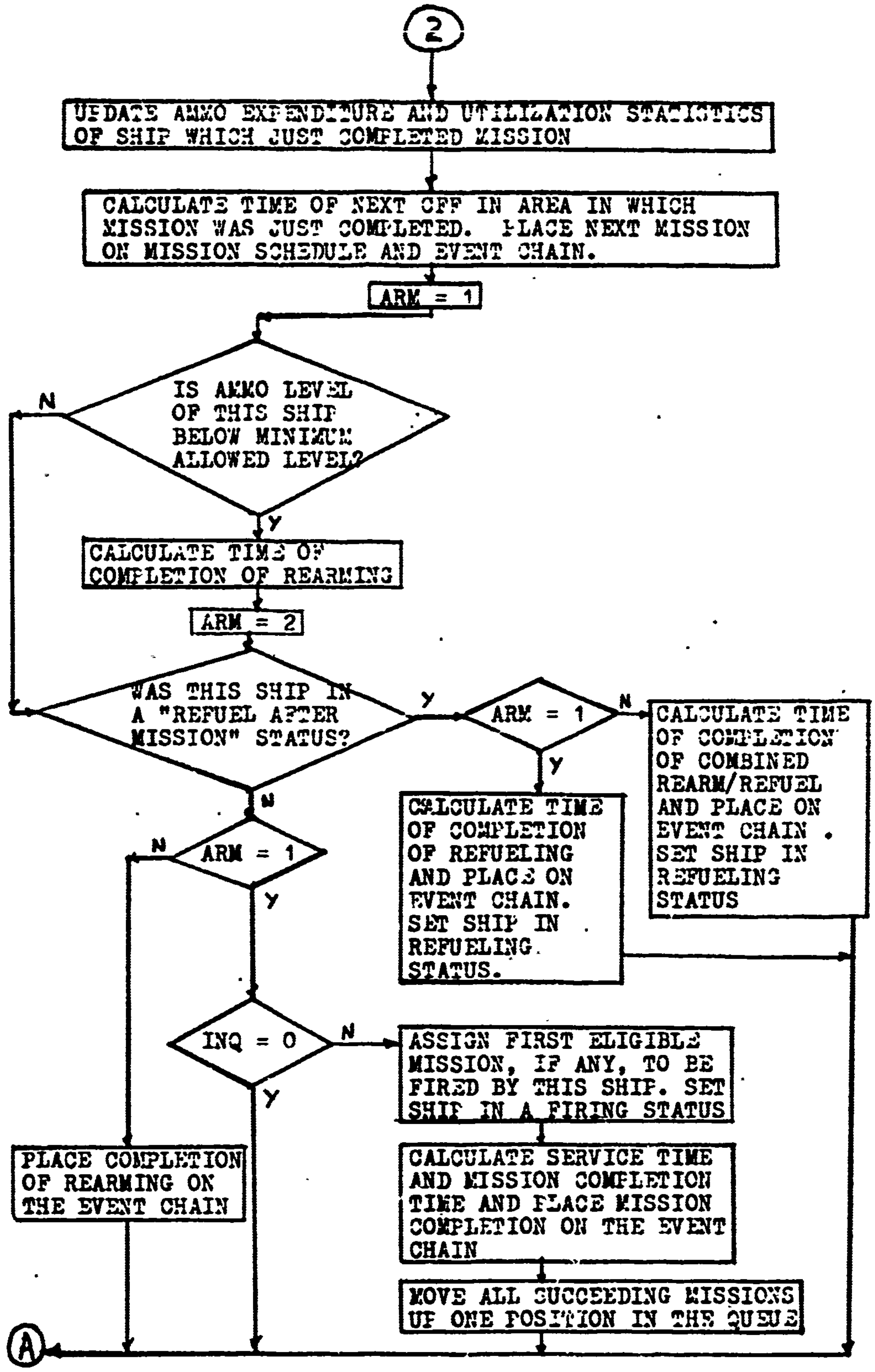
C. OVERALL CONCLUSION

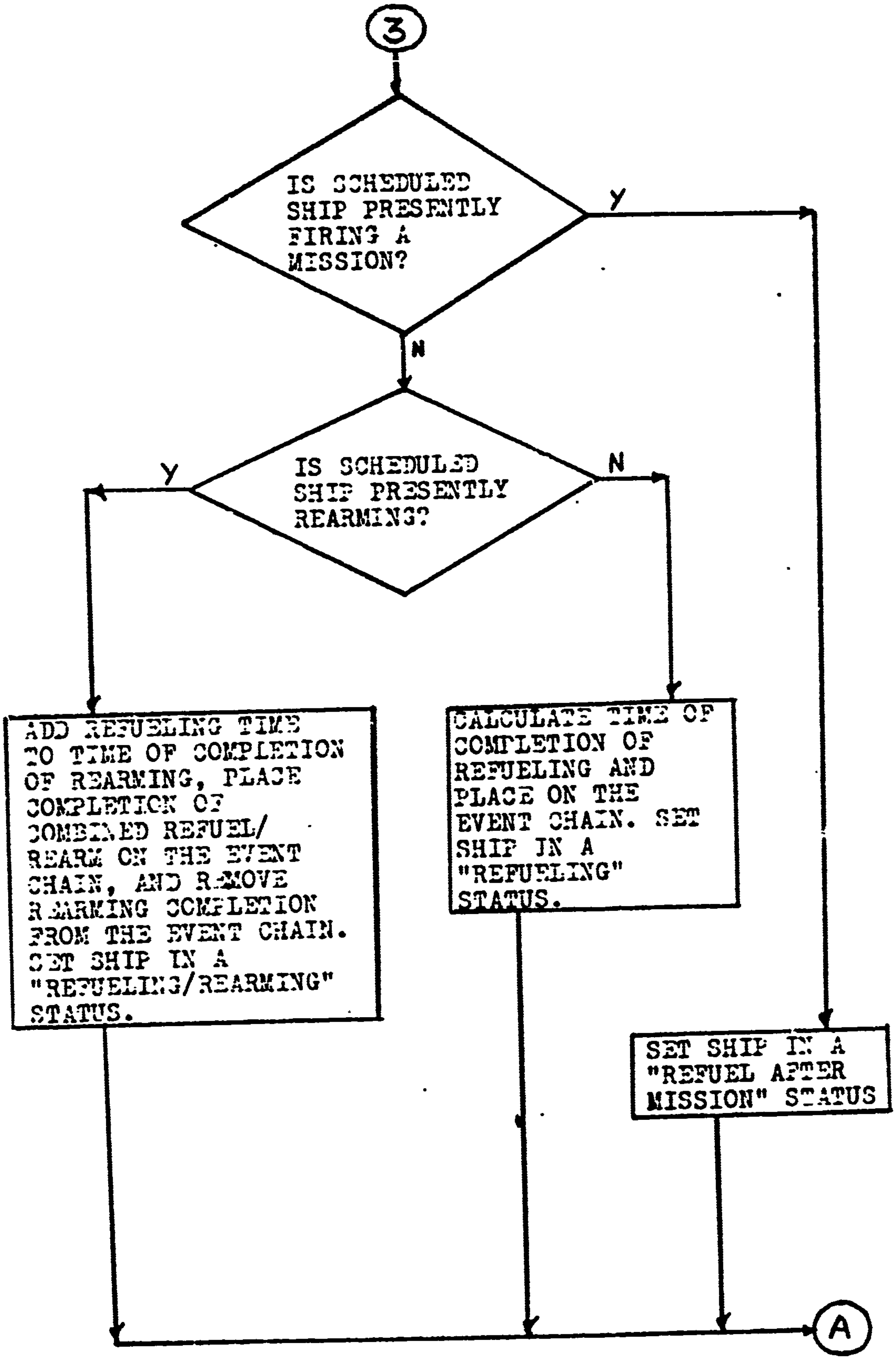
While it is recognized that the model presented in this paper is capable of refinement and extension in several ways, it is considered that the model in its present state is useful as a means of providing general ideas concerning the queueing aspects of a wide variety of user-defined NGFS/SIAF situations. It is also considered that the model can be useful in operational planning, i.e., the model could be used to investigate the effects of locating the waiting pattern in various areas, etc.

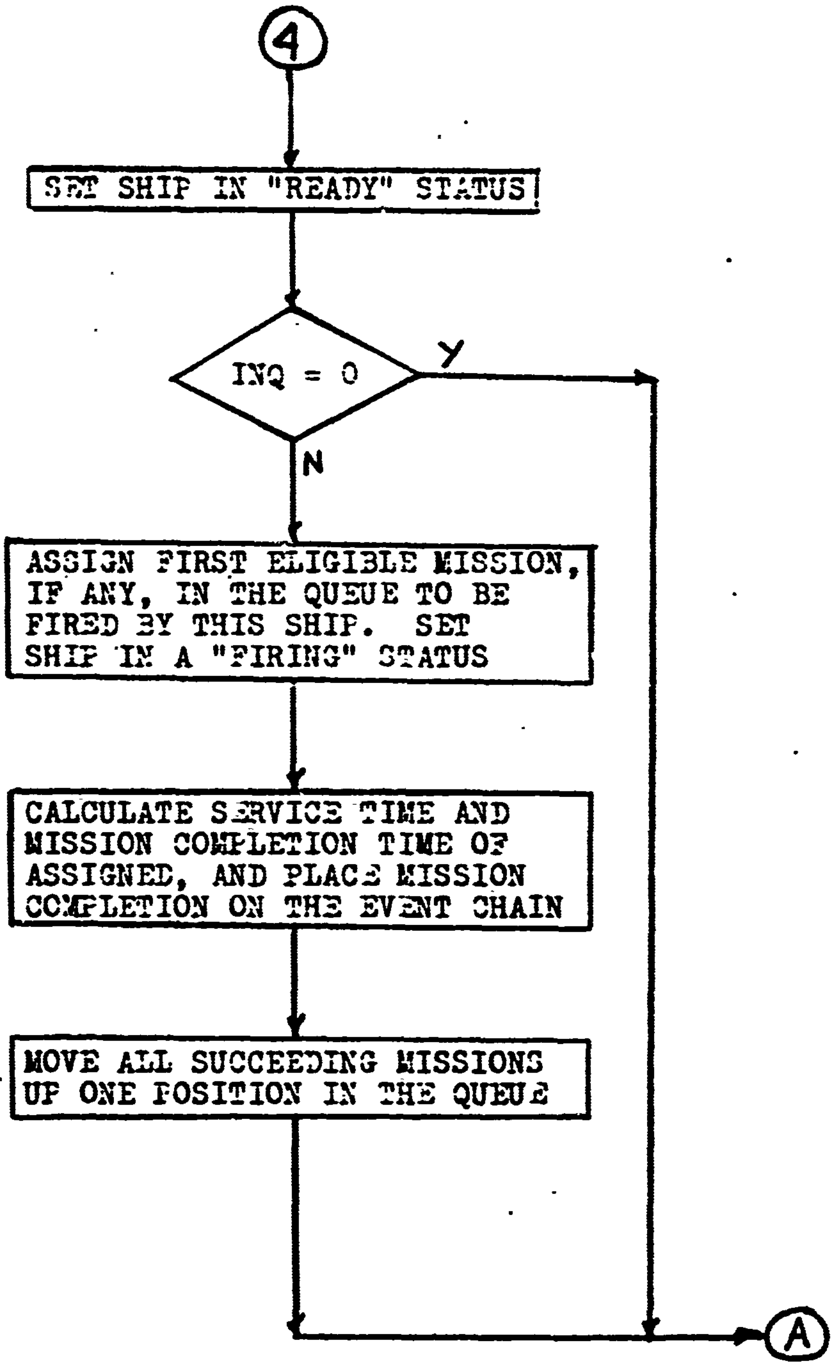
APPENDIX A: COMPUTER PROGRAM GENERALIZED FLOW CHART

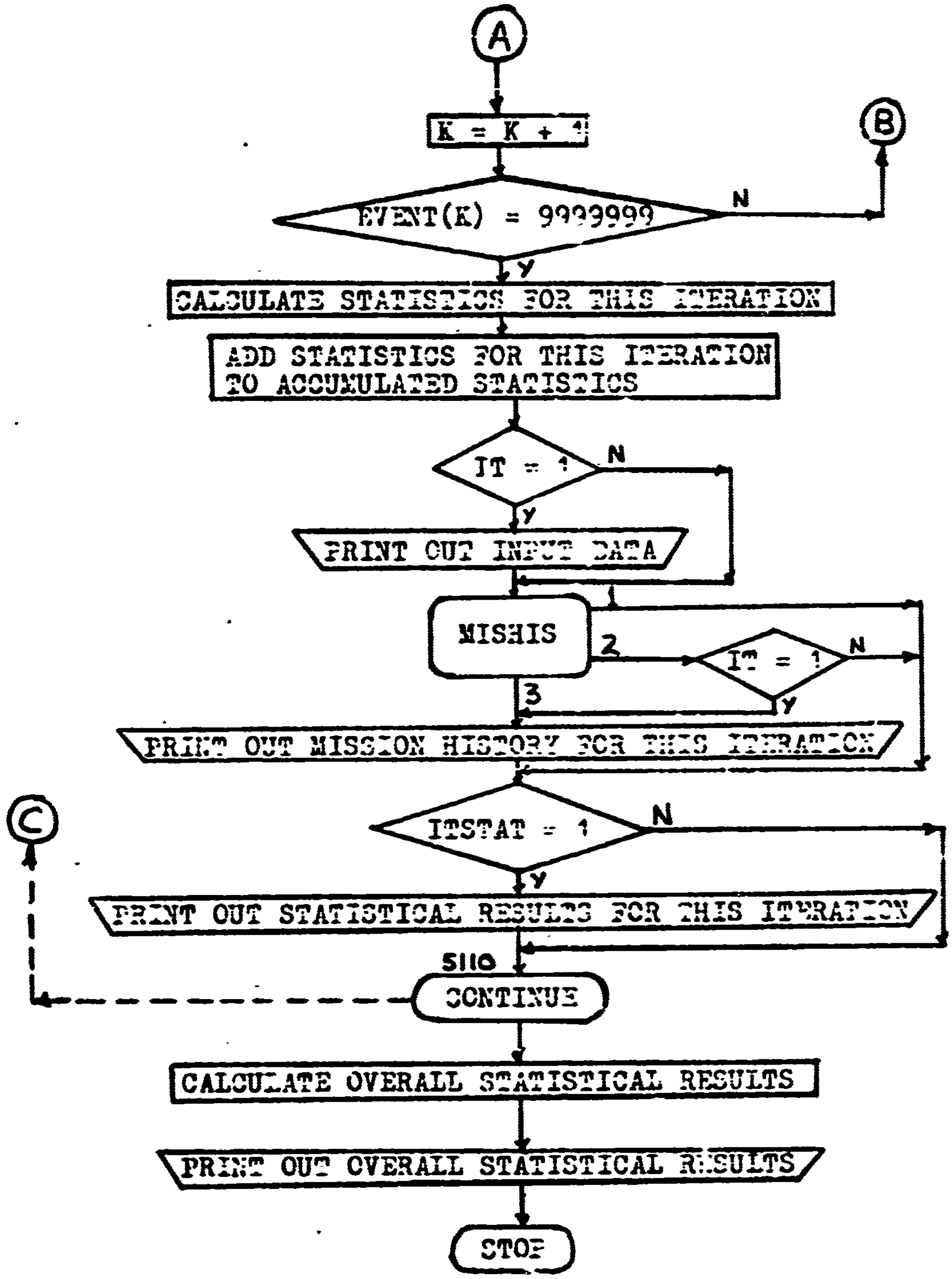



1
CALCULATE TARGET COORDINATES AND TARGET TYPE
ASNDOC = 2
N
Y
DETERMINE MISSION TYPE BASED ON TARGET RANGE ONLY
DETERMINE MISSION TYPE BASED ON RANGE AND TARGET TYPE
CHECK AVAILABILITY OF SHIPS ELIGIBLE TO FIRE THIS TYPE OF MISSION
ANY SHIPS AVAILABLE?
Y
N
CALCULATE TRAVEL DISTANCE OF EACH AVAILABLE SHIP, ASSIGN CLOSEST SHIP TO FIRE THE MISSION, SET ASSIGNED SHIP IN A FIRING STATUS
QDISC = 1, OR TYPE(I) = 3 OR 4, OR INQ = 0
N
Y
PUT MISSION IN THE QUEUE AHEAD OF ALL OTHERS WITH TARGET TYPES 3 OR 4
PUT MISSION AT END OF THE QUEUE
CALCULATE SERVICE TIME AND MISSION COMPLETION TIME, AND PLACE MISSION COMPLETION ON THE EVENT CHAIN
I = I + 1
A


2
UPDATE AMMO EXPENDITURE AND UTILIZATION STATISTICS OF SHIP WHICH JUST COMPLETED MISSION
CALCULATE TIME OF NEXT CFF IN AREA IN WHICH MISSION WAS JUST COMPLETED. PLACE NEXT MISSION ON MISSION SCHEDULE AND EVENT CHAIN.
ARM = 1
IS AMMO LEVEL OF THIS SHIP BELOW MINIMUM ALLOWED LEVEL?
N
Y
CALCULATE TIME OF COMPLETION OF REARMING
ARM = 2
WAS THIS SHIP IN A "REFUEL AFTER MISSION" STATUS?
Y
N
ARM = 1
N
Y
CALCULATE TIME OF COMPLETION OF COMBINED REARM/REFUEL AND PLACE ON EVENT CHAIN. SET SHIP IN REFUELING STATUS
CALCULATE TIME OF COMPLETION OF REFUELING AND PLACE ON EVENT CHAIN. SET SHIP IN REFUELING STATUS.
ARM = 1
N
Y
INQ = 0
N
Y
ASSIGN FIRST ELIGIBLE MISSION, IF ANY, TO BE FIRED BY THIS SHIP. SET SHIP IN A FIRING STATUS
CALCULATE SERVICE TIME AND MISSION COMPLETION TIME AND PLACE MISSION COMPLETION ON THE EVENT CHAIN
MOVE ALL SUCCEEDING MISSIONS UP ONE POSITION IN THE QUEUE
PLACE COMPLETION OF REARMING ON THE EVENT CHAIN
A


3
IS SCHEDULED SHIP PRESENTLY FIRING A MISSION?
Y
N
IS SCHEDULED SHIP PRESENTLY REARMING?
Y
N
ADD REFUELING TIME TO TIME OF COMPLETION OF REARMING, PLACE COMPLETION OF COMBINED REFUEL/REARM ON THE EVENT CHAIN, AND REMOVE REARMING COMPLETION FROM THE EVENT CHAIN. SET SHIP IN A "REFUELING/REARMING" STATUS.
CALCULATE TIME OF COMPLETION OF REFUELING AND PLACE ON THE EVENT CHAIN. SET SHIP IN A "REFUELING" STATUS.
SET SHIP IN A "REFUEL AFTER MISSION" STATUS
A


4
SET SHIP IN "READY" STATUS
INQ = 0
Y
N
ASSIGN FIRST ELIGIBLE MISSION, IF ANY, IN THE QUEUE TO BE FIRED BY THIS SHIP. SET SHIP IN A "FIRING" STATUS
CALCULATE SERVICE TIME AND MISSION COMPLETION TIME OF ASSIGNED, AND PLACE MISSION COMPLETION ON THE EVENT CHAIN
MOVE ALL SUCCEEDING MISSIONS UP ONE POSITION IN THE QUEUE
A


A
K = K + 1
B
EVENT(K) = 9999999
N
Y
CALCULATE STATISTICS FOR THIS ITERATION
ADD STATISTICS FOR THIS ITERATION TO ACCUMULATED STATISTICS
IT = 1
N
Y
PRINT OUT INPUT DATA
MISHIS
2
3
IT = 1
N
Y
PRINT OUT MISSION HISTORY FOR THIS ITERATION
C
ITSTAT = 1
N
Y
PRINT OUT STATISTICAL RESULTS FOR THIS ITERATION
5110
CONTINUE
CALCULATE OVERALL STATISTICAL RESULTS
PRINT OUT OVERALL STATISTICAL RESULTS
STOP

APPENDIX B: COMPLETE COMPUTER PROGRAM LISTING

```
C   OPERATIONS RESEARCH MASTERS THESIS:  "A COMPUTER SIMULATION OF
C       NAVAL GUNFIRE SUPPORT OF SMALL INDEPENDENT ACTION FORCES (SIAF)
C       IN AN INSURGENT-CONTESTED AREA"
C
C
C   BEGIN BY SETTING ASIDE ARRAY STORAGE AND INTIALIZING CERTAIN
C   STATISTIC-KEEPING QUANTITIES
C
      IMPLICIT INTEGER(A-W)
      DIMENSION XCFF(50),XDURAT(50),XCALRT(50),INSERT(50),FIRST(50),
     1          EXTRAC(50),NORTH(50),SOUTH(50),EAST(50),WEST(50),
     2          XPROB1(50),XPROB2(50),XPROB3(50),XPROB4(50),XCUM2(50),
     3          XCUM3(50),MSNSKD(1000),AREA(1000),EWTAR(1000),
     4          RANGE(1000),TYPE(1000),Q(50), SHIPNR(1000),TYPSHP(1000),
     5          MSNCMP(1000),FSTSHT(1000),FSTSHO(1000),TIMFST(1000),
     6          MISTYF(1000),JOINQ(1000),LEAVEQ(1000),QTIME(1000),
     7          ASGN(9,4),UTIL(9,4),FUELTM(9,4),ARMTIM(9,4),INAMM(9,4),
     8          TOTAMX(9,4),XUT855(9),XUT647(9),XUT554(9),XUT538(9),
     9          XCPFST(5),XDOFST(5),XSTART(5),MINLEV(4),AMMLEV(9,4),
     A          APCK(50),XFULSK(9,4,9),XOT855(9),XOT647(9),XOT554(9),
     1          XOT538(9),X85SQR(9),X64SQR(9),X55SQR(9),X53SQR(9),
     2          X85VAR(9),X64VAR(9),X55VAR(9),X53VAR(9),X85DEV(9),
     3          X64DEV(9),X55DEV(9),X53DEV(9),OFULTM(9,4),OARMTM(9,4),
     4          OAMMEX(9,4),XLONG(50),XSHORT(50)
      COMMON NRVENT,K,KOUNT,IR11,IR12,IR13,KR,MINSET,MAXSET,SPEED,
     1       TRAVEL(1000),SERVC(1000),FIRE(1000),SETUP(1000),
     2       AMMEXP(1000),EVENT(2300),EVTYP(2300),EVTMSN(2300),
     3       REPSHP(2300),VAIL(36),STATUS(9,4),FIRTIM(4,4),DENOM(4,4),
     4       MINAMM(4,4),MAXAMM(4,4)
      DATA XOAVWT,XWTSQR,YOAVFS,YFSSQR,XOAVGQ,XAVQSQ,ZOAVFS,ZFSSQR,
     1     XOAVSV,XSVSQR,XCAVTR,XTRSQR,XOAVFR,XFRSQR,XOPRWT,XPERSQ,
     2     XOTL85,XU85SQ,XOTL64,XU64SQ,XOTL55,XU55SQ,XOTL53,XU53SQ,
     3     XOUTIL,XUTSQR/26*0.0/,XOT855,X85SQR,XOT647,X64SQR,XOT554,
     4     X55SQR,XOT538,X53SQR/72*0.0/,OTOTMS,TCMSSQ,OMXINQ,MXQSQR,
     5     OTOTQ,TOQSQR,OMXQTM,QTMSQR/8*0/,XUT855,XUT647,XUT554,
     6     XUT538,X85VAR,X64VAR,X55VAR,X53VAR/72*0.0/,YOAVWT,
     7     YWTSQR,XOAVFS,XFSSQR,XUTL85,XUTL64,XUTL55,XUTL53,XU85DV,
     8     XU64DV,XU55DV,XU53DV/12*0.0/,OMXFST,FSTSQR/2*0/,
     9     OFULTM,OARMTM,OAMMEX/108*0/,XOCLK,XCLKSQ/2*0.0/,
     A     X85DEV,X64DEV,X55DEV,X53DEV/36*0.0/
      DATA R,W/5,6/
```

```
C
C     READ IN MISCELLANEOUS PROGRAM DATA
C
      READ(R,10) NRAREA,NR855,NR647,NR554,NR538,MAX855,MAX647,MAX554,
     1           MAX538,MAXNGF,WTNW,WTNE,NSWAIT,WTDIS,SPEED,MINSET,
     2           MAXSET,HHOUR
   10 FORMAT(I2,4I1,5I5,2I7,2I6,3I2,I4)
      READ(R,11) ASNDOC,ODISC,REPPOL,REFSKD,FINFUL,MISHIS,ITSTAT,NRIT
   11 FORMAT(7I1,I3)
C
C     READ IN PATROL SUBAREA INFORMATION
C
      DO 13 NR=1,NRAREA
      READ(R,12) NORTH(NR),SOUTH(NR),EAST(NR),WEST(NR),XCFF(NR),
     1           XSHORT(NR),XLONG(NR),INSERT(NR),XPROB1(NR),XPROB2(NR),
     2           XPROB3(NR),XPROB4(NR)
   12 FORMAT(4I7,3F5.1,I6,4F5.2)
   13 CONTINUE
C
C     READ IN FIRING TIME PARAMETERS
C
      READ(R,15) FIRTIM,DENOM
   15 FORMAT(16I2/16I5)
C
C     READ IN REFUELING VARIABLES, IF USED
C
      IF(REPPOL.EQ.1) GO TO 28
      READ(R,16) NOMO,COMBO
   16 FORMAT(2I4)
      IF(REFSKD.EQ.2) GO TO 22
      DO 19 K=1,FINFUL
      DO 18 J=1,4
      READ(R,17) (XFULSK(I,J,K),I=1,9)
   17 FORMAT(9F7.2)
   18 CONTINUE
   19 CONTINUE
      GO TO 24
   22 READ(R,23) XCREST,XDDFST,CRINT,DDINT
   23 FORMAT(10F6.2,2I5)
   24 READ(R,25) MINFLC,MAXFLC,MINFLD,MAXFLD
   25 FORMAT(4I5)
C
C     READ IN REARMING VARIABLES, IF USED
C
      READ(R,27) MINLEV,MINARC,MAXARC,MINARD,MAXARD,INAMM
   27 FORMAT(4I6,4I5/9I7/9I7/9I7/9I7)
C
C
```

```
C
      READ IN AMMUNITION EXPENDITURE PARAMETERS
C
   28 READ(R,29) MINAMM,MAXAMM
   29 FORMAT(16I4/16I4)
C
C     INITIALIZE RANDOM NUMBER GENERATORS
C
   30 READ(R,31) IR1,IR2,IR3,IR4,IR5,IR6,IR7,IR8,IR9,IR10,IR11,IR12,
     1            IR13,IR14
   31 FORMAT(14I5)
      KR = 65539
C
C     CALCULATE EXPECTED PATROL DURATION, CALL FOR FIRE RATE, AND
C     CUMULATIVE TARGET TYPE PROBABILITY DISTRIBUTIONS FOR EACH SUBAREA
C
      DO 32 NR=1,NRAREA
      XDUPAT(NR) = (XLONG(NR) + XSHORT(NR))/2
      XCALRT(NR) = XCFF(NR)/(XDURAT(NR)*1440)
      XCUM2(NR) = XPROB1(NR) + XPROB2(NR)
   32 XCUM3(NR) = XCUM2(NR) + XPROB3(NR)
C
C     CALCULATE Y-COORDINATE OF TRAVEL DISTANCE CALCULATION
C
      Y = FLOAT(NSWAIT+WTDIS)/100
      YSQR = Y**2
      YY = FLOAT(WTDIS)/100
      YYSQR = YY**2
C
C
C     ******************************************************************
C
C
C     BEGIN ITERATIVE LOOP TO RUN THE PROBLEM (NRIT) TIMES
C
      DO 5110 IT=1,NRIT
C
C     ZEROIZE CERTAIN STATISTIC-KEEPING QUANTITIES
C
      DO 35 I=1,1000
      JOINQ(I) = 0
      LEAVEQ(I) = 0
      QTIME(I) = 0
      FSTSHT(I) = 0
   35 FSTSHO(I) = 0
      DO 36 I=1,50
   36 ARCK(I) = 0
      DO 38 I=1,9
      DO 37 J=1,4
```

```
      UTIL(I,J) = 0
      FUELTM(I,J) = 0
      ARMTIM(I,J) = 0
      TOTAMX(I,J) = 0
   37 CONTINUE
   38 CONTINUE
      INQ = 0
      MAXINQ = 0
      TOTQ = 0
      MAXQTM = 0
      MAXFST = 0
      TOTSVC = 0
      TOTFAV = 0
      TOFIRE = 0
      TOTFS = 0
      TOFST = 0
      TOTWT = 0
      TOTU85 = 0
      TOTU64 = 0
      TOTU55 = 0
      TOTU53 = 0
      XUTL85 = 0.00
      XUTL64 = 0.00
      XUTL55 = 0.00
      XUTL53 = 0.00
      FUL855 = 0
      FUL647 = 0
      FUL554 = 0
      FUL538 = 0
      ARM855 = 0
      ARM647 = 0
      ARM554 = 0
      ARM538 = 0
C
C     INITIALIZE SHIP STATUS AND AMMO LEVELS
C
      DO 45 T=1,4
      DO 43 S=1,9
      STATUS(S,T) = 1
      AMMLEV(S,T) = INAMM(S,T)
   43 CONTINUE
   45 CONTINUE
C
C     CALCULATE TIME OF FIRST NGFS MISSION AND TIME OF PATROL EXTRACTION
C     FOR EACH PATROL SUBAREA, AND LATEST EXTRACTION TIME
C
      MAXTRC = 0
      DO 50 NR=1,NRAREA
```

```
      IR1 = IR1*KR
      XRN = 0.5 + FLOAT(IR1)*2.328306E-10
      FIRST(NR) = INSERT(NR) - ALOG(XRN)/XCALRT(NR) + 0.5
      IR2 = IR2*KR
      XRN = 0.5 + FLOAT(IR2)*2.328306E-10
      EXTRAC(NR) = INSERT(NR) + (XSHORT(NR) + XRN*(XLONG(NR)
     1             - XSHORT(NR))) * 1440 + 0.5
      IF(EXTRAC(NR).GT.MAXTRC) MAXTRC = EXTRAC(NR)
      IF(FIRST(NR).LE.EXTRAC(NR)) GO TO 50
      FIRST(NR) = 9999999
   50 CONTINUE
C
C     PLACE FIRST MISSIONS ON THE MISSION SCHEDULE AND EVENT CHAIN IN
C     CHRONOLOGICAL ORDER, AND SET TYPE, MISSION NUMBER, AND
C     REPLENISHMENT SHIP INDICATORS FOR THESE EVENTS
C
      DO 52 NR=1,NRAREA
   52 MSNSKD(NR) = FIRST(NR)
      DO 55 J=1,NRAREA
      N = NRAREA - J
      IF(N.EQ.0) GO TO 57
      FLAG = 1
      DO 54 JA=1,N
      IF(MSNSKD(JA).LE.MSNSKD(JA+1)) GO TO 54
      TEMP = MSNSKD(JA)
      MSNSKD(JA) = MSNSKD(JA+1)
      MSNSKD(JA+1) = TEMP
      FLAG = 2
   54 CONTINUE
      IF(FLAG.EQ.1) GO TO 57
   55 CONTINUE
   57 DO 65 ID=1,NRAREA
      EVENT(ID) = MSNSKD(ID)
      EVTYP(ID) = 1
      EVTMSN(ID) = ID
      REPSHP(ID) = 0
C
C     RETRIEVE AREA NUMBER OF THIS MISSION
C
      DO 61 IC=1,NRAREA
      IF(MSNSKD(IC).EQ.FIRST(IC).AND.ARCK(IC).EQ.0) GO TO 63
   61 CONTINUE
      GO TO 65
   63 AREA(ID) = IC
      ARCK(IC) = 1
   65 CONTINUE
C
C
```

```
C     SET NUMBER OF MISSIONS AND NUMBER OF EVENTS GENERATED THUS FAR
C     EQUAL TO NUMBER OF PATROL SUBAREAS
C
         NRMSN = NRAREA
         NRVENT = NRAREA
C
C     CALCULATE THE REFUELING SCHEDULE, IF USED
C
         IF(REFPOL.EQ.1) GO TO 99
         K = 0
         MAXREF = MAXTRC - NOMO
         IF(REFSKD.EQ.2) GO TO 88
C
C     GO THRU HERE IF USER-INPUT SCHEDULE IS USED
C
         DO 79 KK=1,FINFUL
         DO 78 J=1,4
         DO 77 I=1,9
         GO TO(70,71,72,73),J
   70    IF(NR855.LT.I) GO TO 78
         GO TO 74
   71    IF(NR647.LT.I) GO TO 78
         GO TO 74
   72    IF(NR554.LT.I) GO TO 78
         GO TO 74
   73    IF(NR538.LT.I) GO TO 78
   74    GOFUL = 10 * I + J
         REF = 1440 * XFULSK(I,J,KK) + 0.5
         IF(REF.GE.MAXREF) GO TO 77
C
C     PLACE THIS SKED REFUELING ON THE EVENT CHAIN
C
         CALL VENTCH(REF,3,0,GOFUL)
   77    CONTINUE
   78    CONTINUE
   79    CONTINUE
         GO TO 99
C
C     GO THRU HERE IF COMPUTER-CALCULATED SCHEDULE IS USED
C
   88    DO 98 RR=1,4
         GO TO(89,91,92,94),RR
   89    IF((NR855+NR647).EQ.0) GO TO 98
         DO 90 RA=1,5
         XSTART(RA) = XCRFST(RA)
   90    CONTINUE
         MULT = CRINT
         IF(NR855.EQ.0) GO TO 98
```

```
      RRR = NR855
      FAC = 0
      GO TO 95
   91 IF(NR647.EQ.0) GO TO 98
      RRR = NR647
      FAC = NR855
      GO TO 95
   92 IF((NR554+NR538).EQ.0) GO TO 98
      DO 93 RA=1,5
      XSTART(RA) = XDDFST(RA)
   93 CONTINUE
      MULT = DDINT
      IF(NR554.EQ.0) GO TO 98
      RRR = NR554
      FAC = 0
      GO TO 95
   94 IF(NR538.EQ.0) GO TO 98
      RRR = NR538
      FAC = NR554
   95 DO 97 F=1,RRR
      ADD = (F - 1 + FAC) * MULT
      FUL = 10 * F + RR
      DO 96 RB=1,5
      REF = XSTART(RB)*1440 + ADD + 0.5
      IF(REF.GE.MAXREF) GO TO 97
C
C  PLACE THIS SKED REFUEL ON THE EVENT CHAIN
C
      CALL VENTCH(REF,3,0,FUL)
   96 CONTINUE
   97 CONTINUE
   98 CONTINUE
C
C
C            *** START THE PROBLEM ***
C
C
C  INITIALIZE MISSION AND EVENT COUNTERS
C
   99 I = 1
      K = 1
C
C  SET THE PROBLEM TIMER TO TIME OF NEXT EVENT
C
  100 CLOCK = EVENT(K)
      EVT = EVTYP(K)
      GO TO(101,500,785,590),EVT
C
```

```
C   GO THRU HERE IF THE EVENT IS A CALL FOR FIRE
C
C   CALCULATE TARGET RANGE AND E-W COORDINATE
C
  101 KCUNT = 0
      IR3 = IR3*KR
      XRN = 0.5 + FLOAT(IR3)*2.328306E-10
      A = AREA(I)
      RANGE(I) = SOUTH(A) + XRN*(NORTH(A) - SOUTH(A))
      IR4 = IR4*KR
      XRN = 0.5 + FLOAT(IR4)*2.328306E-10
      EWTAR(I) = WEST(A) + XRN * (EAST(A) - WEST(A))
      IF(RANGE(I).GT.MAXNGF) GO TO 215
C
C   DETERMINE TARGET TYPE
C
      IR5 = IR5*KR
      XRN = 0.5 + FLOAT(IR5)*2.328306E-10
      IF(XRN.LE.XPROB1(A)) GO TO 106
      IF(XRN.LE.XCUM2(A)) GO TO 107
      IF(XRN.LE.XCUM3(A)) GO TO 108
      TYPE(I) = 4
      GO TO 109
  106 TYPE(I) = 1
      GO TO 109
  107 TYPE(I) = 2
      GO TO 109
  108 TYPE(I) = 3
C
C   ASSIGN MISSION TYPE ACCORDING TO SHIP ASSIGNMENT DOCTRINE
C
  109 IF(ASNDOC.EQ.2) GO TO 112
C
C   GO THRU HERE IF ASSIGNMENT DOCTRINE IS "ANY SHIP WITH GUNS OF
C   ADEQUATE RANGE MAY FIRE"
C
  111 IF(RANGE(I).GT.MAX554) GO TO 180
      IF(RANGE(I).GT.MAX647) GO TO 210
      IF(RANGE(I).GT.MAX538) GO TO 205
      GO TO 200
C
C   GO THRU HERE IF ASSIGNMENT DOCTRINE IS "BEST EFFECT ON TARGET"
C
  112 TYP = TYPE(I)
      GO TO(115,120,122,111),TYP
  115 IF(RANGE(I).GT.MAX554) GO TO 180
      IF(NR554.EQ.0) GO TO 170
      IF(RANGE(I).GT.MAX538.OR.NR538.EQ.0) GO TO 190
```

```
      GO TO 195
  120 IF(NR538.EQ.0.AND.NR554.EQ.0) GO TO 150
      IF(RANGE(I).GT.MAX538) GO TO 160
      GO TO 140
  122 IF(NR855.NE.0) GO TO 130
      IF(NR647.NE.0) GO TO 135
      IF(RANGE(I).LT.MAX538) GO TO 140
      GO TO 190
  130 IF(RANGE(I).GT.MAX647.OR.NR647.EQ.0) GO TO 180
      GO TO 185
  135 IF(RANGE(I).LT.MAX647) GO TO 185
      GO TO 190
  140 IF(NR538.NE.0) GO TO 195
      GO TO 190
  150 IF(RANGE(I).GT.MAX647.OR.NR647.EQ.0) GO TO 180
      GO TO 185
  160 IF(NR554.EQ.0) GO TO 150
      IF(RANGE(I).GT.MAX554) GO TO 180
      GO TO 190
  170 IF(RANGE(I).GT.MAX538.OR.NR538.EQ.0) GO TO 175
      GO TO 195
  175 IF(RANGE(I).GT.MAX647.OR.NR647.EQ.0) GO TO 180
      GO TO 185
  180 MISTYP(I) = 1
      GO TO 220
  185 MISTYP(I) = 2
      GO TO 225
  190 MISTYP(I) = 3
      GO TO 235
  195 MISTYP(I) = 4
      GO TO 240
  200 MISTYP(I) = 5
      GO TO 250
  205 MISTYP(I) = 6
      GO TO 255
  210 MISTYP(I) = 7
      GO TO 260
  215 MISTYP(I) = 8
      GO TO 9900
C
C     CHECK AVAILABILITY OF APPROPRIATE SHIPS TO FIRE THIS MISSION
C
  220 CALL AVAIL(NR855,1)
      GO TO 270
  225 IF(NR855.EQ.0) GO TO 230
      CALL AVAIL(NR855,1)
  230 CALL AVAIL(NR647,2)
      GO TO 270
```

```
 235 CALL AVAIL(NR554,3)
     GO TO 270
 240 IF(NR554.EQ.0) GO TO 245
     CALL AVAIL(NR554,3)
 245 CALL AVAIL(NR538,4)
     GO TO 270
 250 IF(NR538.EQ.0) GO TO 255
     CALL AVAIL(NR538,4)
 255 IF(NR647.EQ.0) GO TO 260
     CALL AVAIL(NR647,2)
 260 IF(NR554.EQ.0) GO TO 265
     CALL AVAIL(NR554,3)
 265 IF(NR855.EQ.0) GO TO 270
     CALL AVAIL(NR855,1)
 270 IF(KOUNT.EQ.0) GO TO 400
C
C  IF ANY SHIPS AVAILABLE, CALCULATE DISTANCE TO FIRING POSITION FOR
C  EACH AVAILABLE SHIP, AND ASSIGN CLOSEST SHIP TO FIRE THE MISSION
C
     EWDIS = MAXO((WTNE-EWTAR(I)),(EWTAR(I)-WTNW))
     X = FLOAT(EWDIS)/100
     MAXDIS = 100 * SQRT(X**2 + YSQR)
     IF(EWTAR(I).LT.WTNW) GO TO 271
     IF(EWTAR(I).GT.WTNE) GO TO 272
     MINDIS = WTDIS
     GO TO 274
 271 XX = FLOAT(WTNW - EWTAR(I))/100
     GO TO 273
 272 XX = FLOAT(EWTAR(I) - WTNE)/100
 273 MINDIS = 100 * SQRT(XX**2 + YYSQR)
 274 DO 300 JD=1,KOUNT
     IR6 = IR6*KR
     XRN = 0.5 + FLOAT(IR6)*2.328306E-10
     DIST = MINDIS + XRN * (MAXDIS - MINDIS)
     IF(JD.EQ.1) GO TO 275
     IF(DIST.GT.CLOSE) GO TO 300
 275 CLOSE = DIST
     SHIPNR(I) = VAIL(JD)/10
     TYPSHP(I) = MOD(VAIL(JD),10)
 300 CONTINUE
C
C  SET ASSIGNED SHIP IN FIRING STATUS AND RECORD TIME OF ASSIGNMENT
C
     STATUS(SHIPNR(I),TYPSHP(I)) = 2
     ASGN(SHIPNR(I),TYPSHP(I)) = CLOCK
C
C
C
```

```
C  CALCULATE COMPLETION TIME OF THIS MISSION AND PLACE ON EVENT CHAIN
C
      CALL SERVIC(TYPSHP(I),TYPE(I),RANGE(I),I,CLOSE)
      FSTSHT(I) = TRAVEL(I) + SETUP(I)
      IF(FSTSHT(I).GT.MAXFST) MAXFST = FSTSHT(I)
      MSNCMP(I) = CLOCK + SERVC(I)
      CALL VENTCH(MSNCMP(I),2,I,0)
      GO TO 420
C
C  IF NO SHIPS WERE AVAILABLE, PLACE THE MISSION IN THE QUEUE IN ORDER
C  ACCORDING TO SPECIFIED QUEUE DISCIPLINE
C
  400 IF(QDISC.EQ.1.OR.TYPE(I).EQ.3.OR.TYPE(I).EQ.4.OR.INQ.EQ.0)
     1 GO TO 410
      DO 408 IQ=1,INQ
      IF(TYPE(Q(IQ)).EQ.1.OR.TYPE(Q(IQ)).EQ.2) GO TO 408
      QM = INQ - IQ + 1
      DO 406 IQQ=1,QM
      QMM = INQ - IQQ + 1
      Q(QMM+1) = Q(QMM)
  406 CONTINUE
      GO TO 409
  408 CONTINUE
      GO TO 410
  409 Q(IQ) = I
      INQ = INQ + 1
      GO TO 412
  410 INQ = INQ + 1
      Q(INQ) = I
  412 TOTQ = TOTQ + 1
      JOINQ(I) = CLOCK
      IF(INQ.GT.MAXINQ) MAXINQ = INQ
C
C  STEP THE MISSION COUNTER
C
  420 I = I +1
      GO TO 980
C
C  WE GET TO HERE IF EVENT IS A MISSION COMPLETION
C
  500 E = EVTMSN(K)
      S = SHIPNR(E)
      T = TYPSHP(E)
C
C  UPDATE SHIP UTILIZATION AND AMMO EXPENDITURE STATISTICS
C
      TOTAMX(S,T) = TOTAMX(S,T) + AMMEXP(E)
      UTIL(S,T) = UTIL(S,T) + CLOCK - ASGN(S,T)
```

```
C
C     CALCULATE TIME OF NEXT CFF IN AREA IN WHICH MISSION JUST COMPLETED
C     AND PLACE ON EVENT CHAIN AND MISSION SCHEDULE
C
      IR7 = IR7*KR
      XRN = 0.5 + FLOAT(IR7)*2.328306E-10
      NEXT = CLOCK - ALOG(XRN)/XCALRT(AREA(E)) + 0.5
      IF(NEXT.GT.EXTRAC(AREA(E))) GO TO 550
      DO 540 JE=1,NPMSN
      IF(NEXT.GT.MSNSKD(JE)) GO TO 540
      NM = NRMSN - JE + 1
      DO 530 JF=1,NM
      JMM = NRMSN - JF + 1
      MSNSKD(JMM+1) = MSNSKD(JMM)
      AREA(JMM+1) = AREA(JMM)
  530 CONTINUE
      JEE = JE
      GO TO 560
  540 CONTINUE
      GO TO 555
  550 NEXT = 9999999
  555 JEE = NRMSN + 1
  560 MSNSKD(JEE) = NEXT
      AREA(JEE) = AREA(E)
      NRMSN = NRMSN + 1
      CALL VENTCH(NEXT,1,JEE,0)
      IF(REPFOL.EQ.1) GO TO 595
      ARM = 1
C
C     UPDATE AMMO LEVEL OF SHIP WHICH JUST COMPLETED FIRING.  IF AMMO LEVEL
C     IS BELOW MINIMUM ALLOWED FOR SHIP OF THIS TYPE, ASSIGN THE SHIP TO REARM.
C
      AMMLEV(S,T) = AMMLEV(S,T) - AMMEXP(E)
C
C     IF CURRENT TIME IS LATER THAN LATEST ANTICIPATED EXTRACTION TIME.
C     SHIP IS ALLOWED TO REDUCE AMMO LEVEL TO ZERO AND THEN IS REMOVED
C     FROM THE PROBLEM
C
      IF(CLOCK.GE.MAXTRC) GO TO 562
      IF(AMMLEV(S,T).GT.MINLEV(T)) GO TO 570
      GO TO 564
  562 IF(AMMLEV(S,T).GE.1) GO TO 570
      GOARM = 10 * S + T
      COMARM = 9999999
      CALL VENTCH(COMARM,4,0,GOARM)
      STATUS(S,T) = 4
      GO TO 980
C
```

```
C     CALCULATE TIME OF COMPLETION OF REARMING, SET AMMO LEVEL OF REARMING
C     SHIP EQUAL TO ITS INITIAL AMMO LEVEL, AND UPDATE CUMULATIVE
C     REARM TIME STATISTICS
C
  564 IR8 = IR8 * KR
      XRN = 0.5 + FLOAT(IR8) * 2.328306E-10
      IF(T.EQ.3.OR.T.EQ.4) GO TO 565
      COMARM = CLOCK + MINARC + XRN * (MAXARC - MINARC) + 0.5
      AMMLEV(S,T) = INAMM(S,T)
      GO TO 567
  565 COMARM = CLOCK + MINARD + XRN * (MAXARD - MINARD) + 0.5
      AMMLEV(S,T) = INAMM(S,T)
  567 IF(COMARM.GE.MAXTRC) COMARM = MAXTRC
      ARMTIM(S,T) = ARMTIM(S,T) + COMARM - CLOCK
      ARM = 2
C
C     IF THIS SHIP ALSO SKED TO REFUEL, CALCULATE TIME OF COMPLETION OF
C     COMBINED REFUEL/REARM.  IN EITHER CASE, PLACE REPLENISHMENT
C     COMPLETION ON THE EVENT CHAIN AND UPDATE REPL TIME STATISTICS
C
      IF(STATUS(S,T).EQ.3) GO TO 572
      ARM = 1
      STATUS(S,T) = 4
      GOARM = 10 * S + T
      CALL VENTCH(COMARM,4,0,GOARM)
      GO TO 980
  570 IF(STATUS(S,T).EQ.2) GO TO 595
  572 IR9 = IR9 * KR
      XRN = 0.5 + FLOAT(IR9) * 2.328306E-10
      IF(T.EQ.3.OR.T.EQ.4) GO TO 574
      COMFUL = CLOCK + MINFLC + XRN * (MAXFLC - MINFLC) + 0.5
      GO TO 575
  574 COMFUL = CLOCK + MINFLD + XRN * (MAXFLD - MINFLD) + 0.5
  575 IF(COMFUL.GE.MAXTRC) COMFUL = MAXTRC
      FUELTM(S,T) = FUELTM(S,T) + COMFUL - CLOCK
      IF(ARM.EQ.2) GO TO 580
      GOFUL = 10 * S + T
      CALL VENTCH(COMFUL,4,0,GOFUL)
      GO TO 980
  580 COMREP = CLOCK + COMFUL + COMARM - COMBO
      IF(COMREP.GE.MAXTRC) COMREP = MAXTRC
      GOREP = 10 * S + T
      CALL VENTCH(COMREP,4,0,GOREP)
      GO TO 980
C
C     WE GET TO HERE IF EVENT IS A REPLENISHMENT COMPLETION.  SET SHIP IN
C     READY STATUS AND CHECK QUEUE STATUS.
C
```

```
  590 S = REPSHP(K)/10
      T = MOD(REPSHP(K),10)
      STATUS(S,T) = 1
      IF(INQ.EQ.0) GO TO 980
      GUN = T
      GO TO 600
  595 STATUS(S,T) = 1
      IF(INQ.EQ.0) GO TO 980
      GUN = TYPSHP(E)
C
C  CHECK ALL MISSIONS IN THE QUEUE AND ASSIGN THIS SHIP TO FIRE THE
C  FIRST MISSION APPROPRIATE TO ITS TYPE
C
  600 DO 700 IH=1,INQ
      MIS = MISTYP(Q(IH))
      GO TO(610,620,630,640,710,650,660),MIS
  610 IF(GUN.EQ.1) GO TO 710
      GO TO 700
  620 IF(GUN.EQ.1.OR.GUN.EQ.2) GO TO 710
      GO TO 700
  630 IF(GUN.EQ.3) GO TO 710
      GO TO 700
  640 IF(GUN.EQ.3.OR.GUN.EQ.4) GO TO 710
      GO TO 700
  650 IF(GUN.EQ.1.OR.GUN.EQ.2.OR.GUN.EQ.3) GO TO 710
      GO TO 700
  660 IF(GUN.EQ.1.OR.GUN.EQ.3) GO TO 710
  700 CONTINUE
      GO TO 980
C
C  REMOVE THE ASSIGNED MISSION FROM THE QUEUE AND SET ASSIGNED SHIP IN
C  FIRING STATUS
C
  710 P = Q(IH)
      LEAVEQ(P) = CLOCK
      QTIME(P) = LEAVEQ(P) - JOINQ(P)
      IF(QTIME(P).GT.MAXQTM) MAXQTM = QTIME(P)
      STATUS(S,T) = 2
      ASGN(S,T) = CLOCK
      SHIPNR(P) = S
      TYPSHP(P) = T
C
C  CALCULATE DISTANCE TO FIRING POSITION OF ASSIGNED MISSION, TIME OF
C  FIRST SHOT, AND MISSION COMPLETION TIME, AND PLACE MISSION
C  COMPLETION TIME ON THE EVENT CHAIN
C
      IF(EVTYP(K).EQ.2) GO TO 715
      RUN = WTDIS + NSWAIT/2
```

```
      GO TO 720
  715 RUN = IABS(EWTAR(E)-EWTAR(P))
  720 CALL SERVIC(TYPSHP(P),TYPE(P),RANGE(P),P,RUN)
      FSTSHO(P) = TRAVEL(P) + QTIME(P) + SETUP(P)
      IF(FSTSHO(P).GT.MAXFST) MAXFST = FSTSHO(P)
      MSNCMP(P) = CLOCK + SERVC(P)
      CALL VENTCH(MSNCMP(P),2,P,0)
C
C     MOVE ALL MISSIONS FOLLOWING THE ASSIGNED MISSION UP ONE POSITION IN
C     THE QUEUE
C
      INQ = INQ - 1
      IF(IH.EQ.(INQ+1).OR.INQ.EQ.0) GO TO 980
      DO 775 IM=IH,INQ
      Q(IM) = Q(IM+1)
  775 CONTINUE
      GO TO 980
C
C     WE GET TO HERE IF EVENT IS A SCHEDULED REFUELING
C
  785 S = REPSHP(K)/10
      T = MOD(REPSHP(K),10)
C
C     IF SHIP SCHEDULED TO REFUEL IS FIRING A MISSION, SET SHIP IN A
C     "REFUEL AFTER MISSION" STATUS
C
      IF(STATUS(S,T).EQ.2) GO TO 792
C
C     IF SHIP SCHEDULED TO REFUEL IS PRESENTLY REARMING, DETERMINE WHICH
C     EVENT IS THE COMPLETION OF REARMING OF THIS SHIP, ADD FUELING TIME
C     TO REARM COMPLETION, REMOVE REARM COMPLETION FROMM EVENT CHAIN, AND
C     PLACE COMBINED REARM/REFUEL COMPLETION ON THE EVENT CHAIN
C
      IF(STATUS(S,T).EQ.4) GO TO 793
C
C     IF SHIP SCHEDULED TO REFUEL IS NEITHER FIRING OR REARMING, PLACE IN
C     "REFUELING" STATUS AND CALCULATE FUELING COMPLETION TIME AND PLACE ON
C     THE EVENT CHAIN
C
      IR10 = IR1C * KR
      XRN = 0.5 + FLOAT(IR10) * 2.328306E-10
      IF(T.EQ.3.OR.T.EQ.4) GO TO 790
      COMFUL = CLOCK + MINFLC + XRN * (MAXFLC - MINFLC) + 0.5
      GO TO 791
  790 COMFUL = CLOCK + MINFLD + XRN * (MAXFLD - MINFLD) + 0.5
  791 IF(COMFUL.GE.MAXTRC) COMFUL = MAXTRC
      FUELTM(S,T) = FUELTM(S,T) + COMFUL - CLOCK
      CALL VENTCH(COMFUL,4,0,REPSHP(K))
```

```
  792 STATUS(S,T) = 3
      GO TO 980
  793 STATUS(S,T) = 3
      FIG = 10 * S + T
      NEX = K + 1
      LAS = NRVENT
      DO 799 EEE=NEX,LAS
      IF(REPSHP(EEE).NE.FIG.OR.EVTYP(EEE).NE.4) GO TO 799
      IR14 = IR14 * KR
      XRN = 0.5 + FLOAT(IR14) * 2.328306E-10
      IF(T.EQ.3.OR.T.EQ.4) GO TO 794
      COMFUL = MINFLC + XRN * (MAXFLC - MINFLC) + 0.5
      GO TO 795
  794 COMFUL = MINFLD + XRN * (MAXFLD - MINFLD) + 0.5
  795 COMREP = EVENT(EEE) + COMFUL - COMBO
      ARMTIM(S,T) = ARMTIM(S,T) - COMBO/2
      FUELTM(S,T) = FUELTM(S,T) + COMFUL - COMBO/2
      IF(COMREP.GE.MAXTRC) COMREP = MAXTRC
      IF(EEE.EQ.NRVENT) GO TO 797
      CALL VENTCH(COMREP,4,0,FIG)
      NRVENT = NRVENT - 1
C
C     MOVE ALL EVENTS FOLLOWING THE REMOVED REARM COMPLETION UP ONE
C     POSITION ON THE EVENT CHAIN
C
      DO 796 BB=EEE,NRVENT
      EVENT(BB) = EVENT(BB+1)
      EVTYP(BB) = EVTYP(BB+1)
      EVTMSN(BB) = EVTMSN(BB+1)
      REPSHP(BB) = REPSHP(BB+1)
  796 CONTINUE
      GO TO 980
  797 EVENT(NRVENT) = COMREP
      GO TO 980
  799 CONTINUE
C
C     STEP THE EVENT COUNTER
C
  980 K = K + 1
C
C     IF THE NEXT EVENT IS A BOGUS EVENT, THE PROBLEM IS COMPLETE.
C     IF NOT, STEP TO TIME OF NEXT EVENT
C
  990 IF(EVENT(K).GE.9999999) GO TO 1000
      GO TO 100
C
C
C
```

```
C
C         *** STATISTICAL CALCULATIONS ***
C
C  CALCULATE STATISTICS FOR THIS ITERATION
C
 1000 TOTMSN = I - 1
      DO 1010 IJ = 1,TOTMSN
      TOTWT = TOTWT + QTIME(IJ)
      TOTFS = TOTFS + FSTSHT(IJ)
      TOFST = TOFST + FSTSHO(IJ)
      TOTSVC = TOTSVC + SERVC(IJ)
      TOTRAV = TOTRAV + TRAVEL(IJ)
      TOFIRE = TOFIRE + FIRE(IJ)
 1010 CONTINUE
      IF(TOTQ.EQ.0) GO TO 1011
      XAVGWT = FLOAT(TOTWT)/TOTQ
      YAVFST = FLOAT(TOFST)/TOTQ
      GO TO 1012
 1011 XAVGWT = 0.00
      YAVFST = 0.0
 1012 YAVGWT = FLOAT(TOTWT)/TOTMSN
      XAVGQ = FLOAT(TOTWT)/CLOCK
      XAVFST = FLOAT(TOTFS)/(TOTMSN-TOTQ)
      ZAVFST = (TOTFS+TOFST)/FLOAT(TOTMSN)
      XAVSVC = FLOAT(TOTSVC)/TOTMSN
      XAVTRV = FLOAT(TOTRAV)/TOTMSN
      XAVFIR = FLOAT(TOFIRE)/TOTMSN
      XPERWT = 100 * FLOAT(TOTQ)/TOTMSN
C
C  ADD STATISTICS FOR THIS ITERATION TO ACCUMULATED STATISTICS
C
      XOCLK = XOCLK + FLOAT(CLOCK)/1440
      XCLKSQ = XCLKSQ + (FLOAT(CLOCK)/1440)**2
      OTOTMS = OTOTMS + TOTMSN
      TCMSSQ = TCMSSQ + TOTMSN**2
      OMXINO = OMXINO + MAXINO
      MXQSQR = MXQSQR + MAXINO**2
      OTOTQ = OTOTQ + TOTQ
      TOQSQR = TOQSQR + TOTQ**2
      OMXQTM = OMXQTM + MAXQTM
      QTMSQR = QTMSQR + MAXQTM**2
      OMXFST = OMXFST + MAXFST
      FSTSQR = FSTSQR + MAXFST**2
      XOAVWT = XOAVWT + XAVGWT
      XWTSQR = XWTSQR + XAVGWT**2
      YOAVFS = YOAVFS + YAVFST
      YFSSQR = YFSSQR + YAVFST**2
      YOAVWT = YOAVWT + YAVGWT
```

```
      YWTSQR = YWTSQR + YAVGWT**2
      XOAVGQ = XOAVGQ + XAVGQ
      XAVQSQ = XAVQSQ + XAVGQ**2
      XOAVFS = XOAVFS + XAVFST
      XFSSQR = XFSSQR + XAVFST**2
      ZOAVFS = ZOAVFS + ZAVFST
      ZFSSQR = ZFSSQR + ZAVFST**2
      XOAVSV = XOAVSV + XAVSVC
      XSVSQR = XSVSQR + XAVSVC**2
      XOAVTR = XOAVTR + XAVTRV
      XTRSQR = XTRSQR + XAVTRV**2
      XOAVFR = XOAVFR + XAVFIR
      XFRSQR = XFRSQR + XAVFIR**2
      XOPRWT = XOPRWT + XPERWT
      XPERSQ = XPERSQ + XPERWT**2
C
C     CALCULATE UTILIZATION STATISTICS FOR THIS ITERATION AND ADD TO
C     ACCUMULATED STATISTICS, AND ADD REARMING AND REFUELING STATISTICS
C     FOR THIS ITERATION TO ACCUMULATED STATISTICS
C
      IF(NR855.EQ.0) GO TO 1030
      DO 1020 IK=1,NR855
      XUT855(IK) = UTIL(IK,1)/(FLOAT(CLOCK)-FUELTM(IK,1)-ARMTIM(IK,1))
      XOT855(IK) = XOT855(IK) + XUT855(IK)
      X85SQR(IK) = X85SQR(IK) + XUT855(IK)**2
      TOTU85 = TOTU85 + UTIL(IK,1)
      OFULTM(IK,1) = OFULTM(IK,1) + FUELTM(IK,1)
      OARMTM(IK,1) = OARMTM(IK,1) + ARMTIM(IK,1)
      OAMMEX(IK,1) = OAMMEX(IK,1) + TOTAMX(IK,1)
      FUL855 = FUL855 + FUELTM(IK,1)
      ARM855 = ARM855 + ARMTIM(IK,1)
 1020 CONTINUE
      XUTL85 = FLOAT(TOTU85)/((NR855*CLOCK) - FUL855 - ARM855)
 1030 IF(NR647.EQ.0) GO TO 1050
      DO 1040 IK=1,NR647
      XUT647(IK) = UTIL(IK,2)/(FLOAT(CLOCK)-FUELTM(IK,2)-ARMTIM(IK,2))
      XOT647(IK) = XOT647(IK) + XUT647(IK)
      X64SQR(IK) = X64SQR(IK) + XUT647(IK)**2
      TOTU64 = TOTU64 + UTIL(IK,2)
      OFULTM(IK,2) = OFULTM(IK,2) + FUELTM(IK,2)
      OARMTM(IK,2) = OARMTM(IK,2) + ARMTIM(IK,2)
      OAMMEX(IK,2) = OAMMEX(IK,2) + TOTAMX(IK,2)
      FUL647 = FUL647 + FUELTM(IK,2)
      ARM647 = ARM647 + ARMTIM(IK,2)
 1040 CONTINUE
      XUTL64 = FLOAT(TOTU64)/((NR647*CLOCK) - FUL647 - ARM647)
 1050 IF(NR554.EQ.0) GO TO 1070
      DO 1060 IK=1,NR554
```

```
      XUT554(IK) = UTIL(IK,3)/(FLOAT(CLOCK)-FUELTM(IK,3)-ARMTIM(IK,3))
      XOT554(IK) = XOT554(IK) + XUT554(IK)
      X55SQR(IK) = X55SQR(IK) + XUT554(IK)**2
      TOTU55 = TOTU55 + UTIL(IK,3)
      OFULTM(IK,3) = OFULTM(IK,3) + FUELTM(IK,3)
      OARMTM(IK,3) = OARMTM(IK,3) + ARMTIM(IK,3)
      OAMMEX(IK,3) = OAMMEX(IK,3) + TOTAMX(IK,3)
      FUL554 = FUL554 + FUELTM(IK,3)
      ARM554 = ARM554 + ARMTIM(IK,3)
 1060 CONTINUE
      XUTL55 = FLOAT(TOTU55)/((NR554*CLOCK) - FUL554 - ARM554)
 1070 IF(NR538.EQ.0) GO TO 5000
      DO 1080 IK=1,NR538
      XUT538(IK) = UTIL(IK,4)/(FLOAT(CLOCK)-FUELTM(IK,4)-ARMTIM(IK,4))
      XOT538(IK) = XOT538(IK) + XUT538(IK)
      X53SQR(IK) = X53SQR(IK) + XUT538(IK)**2
      TOTU53 = TOTU53 + UTIL(IK,4)
      OFULTM(IK,4) = OFULTM(IK,4) + FUELTM(IK,4)
      OARMTM(IK,4) = OARMTM(IK,4) + ARMTIM(IK,4)
      OAMMEX(IK,4) = OAMMEX(IK,4) + TOTAMX(IK,4)
      FUL538 = FUL538 + FUELTM(IK,4)
      ARM538 = ARM538 + ARMTIM(IK,4)
 1080 CONTINUE
      XUTL53 = FLOAT(TOTU53)/((NR538*CLOCK) - FUL538 - ARM538)
 5000 TOTREP = FUL855 + ARM855 + FUL647 + ARM647 + FUL554 + ARM554 +
     1         FUL538 + ARM538
      TOTUTL = TOTU85 + TOTU64 + TOTU55 + TOTU53
      XUTILZ = FLOAT(TOTUTL)/((NR855+NR647+NR554+NR538)*CLOCK - TOTREP)
      XOTL85 = XOTL85 + XUTL85
      XU85SQ = XU85SQ + XUTL85**2
      XOTL64 = XOTL64 + XUTL64
      XU64SQ = XU64SQ + XUTL64**2
      XOTL55 = XOTL55 + XUTL55
      XU55SQ = XU55SQ + XUTL55**2
      XOTL53 = XOTL53 + XUTL53
      XU53SQ = XU53SQ + XUTL53**2
      XOUTIL = XOUTIL + XUTILZ
      XUTSQR = XUTSQR + XUTILZ**2
C
C  IF THIS IS THE FIRST ITERATION, PRINT OUT INPUT DATA
C
      IF(IT.NE.1) GO TO 5014
      MAXNR = MAX0(NR855,NR647,NR554,NR538)
      WRITE(W,7000)
 7000 FORMAT('1',T33,'*** INPUT DATA ***'///)
      WRITE(W,7050) NR855,NR647,NR554,NR538
 7050 FORMAT(' ',T12,'NUMBER OF 8"/55 SHIPS PRESENT = ',I1/' ',T12,'NUMB
     1ER OF 6"/47 SHIPS PRESENT = ',I1/' ',T12,'NUMBER OF 5"/54 SHIPS PR
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     2ESENT = ',I1/' ',T12,'NUMBER OF 5"/38 SHIPS PRESENT = ',I1///)
      WRITE(W,7100) MAX855,MAX647,MAX554,MAX538
 7100 FORMAT(' ',T12,'MAX RANGE OF 8"/55 GUN = ',I5,T43,'YDS'/' ',T12,'M
     1AX RANGE OF 6"/47 GUN = ',I5,T43,'YDS'/' ',T12,'MAX RANGE OF 5"/54
     2 GUN = ',I5,T43,'YDS'/' ',T12,'MAX RANGE OF 5"/38 GUN = ',I5,T43,
     3'YDS'///)
      EWWAIT = WTNE-WTNW
      WRITE(W,7125) WTNW,WTDIS,EWWAIT,NSWAIT
 7125 FORMAT(' ',T12,'DISTANCE OF WESTERN EDGE OF WAITING PATTERN FROM Y
     1-AXIS = ',I5,T76,'YDS'/' ',T12,'DISTANCE OF NORTHERN EDGE OF WAITI
     2NG PATTERN FROM GUNLINE = ',I5,T78,'YDS'/' ',T12,'E-W LENGTH OF WA
     3ITING PATTERN = ',I5,T50,'YDS'/' ',T12,'N-S LENGTH OF WAITING PATT
     4ERN = ',I5,T50,'YDS'///)
      WRITE(W,7150) SPEED,MINSET,MAXSET
 7150 FORMAT(' ',T12,'SPEED TO FIRING POSITION = ',I2,T42,'KNOTS'/' ',
     1T12,'MIN SETUP TIME = ',I2,T32,'MINS'/' ',T12,'MAX SETUP TIME = ',
     2I2,T32,'MINS'///)
      WRITE(W,7200) ASNDOC,QDISC,REPPOL,REFSKD
 7200 FORMAT(' ',T12,'ASSIGNMENT DOCTRINE: ',I1/' ',T12,'QUEUE DISCIPLIN
     1E: ',I1/' ',T12,'REPLENISHMENT POLICY: ',I1/' ',T12,'TYPE OF FUELI
     2NG SCHEDULE USED: ',I1////)
      WRITE(W,7250)
 7250 FORMAT(' ',T18,'* COMPONENTS OF MEAN FIRING TIME *'//'0',T12,'MEAN
     1 FIRING TIME DUE TO TARGET TYPE:  (MINUTES FROM TABLE BELOW)'//
     2' ',T31,'TARGET TYPE'/' ',T12,'TYPE SHIP      1      2      3      4'
     3//)
      DO 7310 I=1,4
      WRITE(W,7300) I,(FIRTIM(I,J),J=1,4)
 7300 FORMAT(' ',14X,I1,5X,4I6)
 7310 CONTINUE
      WRITE(W,7350)
 7350 FORMAT(' ',' ','///' ',T12,'DENOMINATOR OF RANGE FACTOR: (FROM TABL
     1E BELOW)'//' ',T33,'TARGET TYPE'/' ',T12,'TYPE SHIP       1      2
     2      3      4'//)
      DO 7410 I=1,4
      WRITE(W,7400) I,(DENOM(I,J),J=1,4)
 7400 FORMAT(' ',14X,I1,5X,4I7)
 7410 CONTINUE
      IF(REPPOL.EQ.1) GO TO 7840
 7440 WRITE(W,7450)
 7450 FORMAT('1',T37,'* AREA INFORMATION *'////' ',T44,'EXP PATROL',T67,
     1'TARGET TYPE'/' ',T10,'AREA',T22,'AREA BOUNDARIES',
     2 T45,'DURATION   EXP NR    PROBABILITIES'/' ',T11,'NR    NORTH   SO
     3UTH   WEST   EAST    MIN   MAX    OF OFF    1    2    3    4'//)
      DO 7510 I=1,NFAREA
      WRITE(W,7500) I,NORTH(I),SOUTH(I),WEST(I),EAST(I),XSHORT(I),
     1              XLONG(I),XOFF(I),XPROB1(I),XPROB2(I),XPROB3(I),
     2              XPROB4(I)
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7500 FORMAT(' ',9X,I2,1X,4I7,1X,2F5.1,2X,F6.1,1X,4F5.2)
7510 CONTINUE
     IF(REPPOL.EQ.1) GO TO 5014
     WRITE(W,7550)
7550 FORMAT('1',T27,'* REFUELING AND REARMING DATA *'///)
     WRITE(W,7600)
7600 FORMAT(' ',T12,'OFF-STATION TIME PARAMETERS:'/' ',T16,'(MINUTES OF
    1F STATION PER EVOLUTION FROM TABLE BELOW)'//' ',T20,'CRUISERS',
    2T47,'DESTROYERS'/' ',T15,'REFUEL        REARM',T43,'REFUEL       RE
    OARM'/' ',T14,'MIN  MAX      MIN  MAX        MIN  MAX      MIN  MAX'/)
     WRITE(W,7650) MINFLC,MAXFLC,MINARC,MAXARC,MINFLD,MAXFLD,MINARD,
    1              MAXARC
7650 FORMAT('C',10X,2I5,3X,2I5,5X,2I5,3X,2I5///)
     WRITE(W,7700)
7700 FORMAT(' ',T12,'INITIAL AMMUNITION LEVELS:'/' ',T16,'(ROUNDS ON BO
    1ARD FROM BELOW TABLE)'//' ',T38,'SHIP TYPE'/' ',T12,'SHIP NR
    28"/55      6"/47       5"/54       5"/38'//)
     DO 7760 I=1,MAXNR
     WRITE(W,7750) I,(INAMM(I,J),J=1,4)
7750 FORMAT(' ',13X,I1,4X,4I10)
7760 CONTINUE
     WRITE(W,7800) MINLEV(1),MINLEV(2),MINLEV(3),MINLEV(4)
7800 FORMAT(' ',' '////' ',T12,'MINIMUM ALLOWED AMMUNITION LEVELS ='//
    1' ',T12,'8"/55: ',I5,T25,'RDS'/' ',T12,'6"/47: ',I5,T25,'RDS'/' ',
    2T12,'5"/54: ',I5,T25,'RDS'/' ',T12,'5"/38: ',I5,T25,'RDS'////)
     GO TO 7845
7840 WRITE(W,7841)
7841 FORMAT(' ',' '///)
7845 WRITE(W,7850)
7850 FORMAT(' ',T12,'EXPECTED AMMUNITION EXPENDITURES: '/' ',T16,'(ROUN
    1DS PER MINUTE PER MISSION)'//' ',T40,'TARGET TYPE'/' ',T12,'TYPE S
    2HIP',6X,'1',11X,'2',11X,'3',11X,'4'/' ',T23,'MIN  MAX     MIN  MAX
    3  MIN  MAX     MIN  MAX'//)
     DO 7910 I=1,4
     WRITE(W,7900) I,(MINAMM(I,J),MAXAMM(I,J),J=1,4)
7900 FORMAT(' ',14X,I1,4X,2I5,2X,2I5,2X,2I5,2X,2I5)
7910 CONTINUE
     IF(REPPOL.EQ.1) GO TO 7440
C
C  PRINT OUT MISSION HISTORY FOR THIS ITERATION IF DESIRED
C
5014 IF(MISHIS.EQ.2.AND.IT.NE.1) GO TO 5101
     IF(MISHIS.EQ.1) GO TO 5101
     WRITE(W,5015) IT
5015 FORMAT('1',T51,'*** MISSION HISTORY ***'//' ',T51,' ITERATION NUMB
    1ER ',I3///)
     WRITE(W,5020)
5020 FORMAT                                    (' ',T62,'TIME OF     TI
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     1ME',T91,'TIME OF     ACTUAL     TIME'/' ',T62,'CALL FOR  AWAITING  T
     2RAVEL  FIRST SHOT  FIRING   MISSION'/' ',T5,'MISSION   AREA    TARG
     3ET  MISSION  RANGE    SHIP ASSIGNED    FIRE    ASSGNMT    TIME   (M
     4INS FROM   TIME   COMPLETED'/' ',T6,'NUMBER   NUMBER   TYPE    TYPE
     5    (YDS)      TYPE     NR      (DTG)      (MINS)    (MINS)     CFF)
     6 (MINS)      (DTG)'//)
      DO 5100 I=1,TOTMSN
      IF(FSTSHT(I).EQ.0) GO TO 5025
      TIMFST(I) = FSTSHT(I)
      GO TO 5030
 5025 TIMFST(I) = FSTSHO(I)
 5030 MSNSKD(I) = MSNSKD(I) + HHOUR
      DAYS = MSNSKD(I)/1440
      RMDR = MOD(MSNSKD(I),1440)
      HRS = RMDR/60
      MINS = MOD(RMDR,60)
      MSNSKD(I) = (DAYS+1)*10000 + HRS*100 + MINS
      MSNCMP(I) = MSNCMP(I) + HHOUR
      DAYS = MSNCMP(I)/1440
      RMDR = MOD(MSNCMP(I),1440)
      HRS = RMDR/60
      MINS = MOD(RMDR,60)
      MSNCMP(I) = (DAYS+1)*10000 + HRS*100 + MINS
 5040 WRITE(W,5050) I,AREA(I),TYPE(I),MISTYP(I),RANGE(I),TYPSHP(I),
     1              SHIPNR(I),MSNSKD(I),OTIME(I),TRAVEL(I),TIMFST(I),
     2              FIRE(I),MSNCMP(I)
 5050 FORMAT(' ',5X,I3,6X,I2,7X,I1,7X,I1,5X,I5,6X,I1,5X,I1,6X,I6,3X,I5,
     16X,I3,5X,I5,6X,I4,5X,I6)
 5100 CONTINUE
C
C   PRINT OUT STATISTICAL RESULTS FOR THIS ITERATION, IF DESIRED
C
 5101 IF(ITSTAT.EQ.2) GO TO 5110
      DAYS = CLOCK/1440
      RMDR = MOD(CLOCK,1440)
      HRS = RMDR/60
      MINS = MOD(RMDR,60)
      WRITE(W,5195) IT,DAYS,HRS,MINS,TOTMSN
 5195 FORMAT('1',T30,'**** STATISTICAL RESULTS ****'/'0',T35,'ITERATION
     1NUMBER',I4          ///' ',10X,'TOTAL PROBLEM TIME  =  ',I2,1X,'DA
     2YS, ',I2,1X,'HOURS, ',I2,1X,'MINUTES'//' ',10X,'TOTAL NUMBER OF MI
     3SSIONS FIRED  = ',I5///)
      WRITE(W,5200) XAVGWT,YAVGWT,MAXOTM,XAVGQ,MAXINQ,TOTQ,XPERWT,
     1              YAVFST,XAVFST,ZAVFST,MAXFST,XAVTRV,XAVFIR,XAVSVC
 5200 FORMAT                                          (' ',10X,'AV
     1ERAGE WAITING TIME (INCL ONLY MISSIONS REQUIRED TO WAIT)  = ',F6.1
     2,T81,'MINS'/'0',10X,'AVERAGE WAITING TIME (ALL MISSIONS)  =  ',
     3F5.1,T58,'MINS'/'0',10X,'MAXIMUM WAITING TIME  = ',I6,T43,'MINS'//
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     4'0',10X,'AVERAGE NUMBER OF MISSIONS AWAITING ASSIGNMENT  =  ',F5.2
     5/'0',10X,'MAXIMUM NUMBER OF MISSIONS AWAITING ASSIGNMENT  =  ',I3/
     6'0',10X,'TOTAL NUMBER OF MISSIONS WHICH WERE REQUIRED TO WAIT FOR
     7ASSIGNMENT  =  ',I3/'0',10X,'PERCENT OF MISSIONS WHICH WERE REQUIR
     8ED TO WAIT FOR ASSIGNMENT  =',F5.1///'0',10X,'AVERAGE TIME FROM CA
     9LL FOR FIRE (CFF) UNTIL FIRST SHOT (MISSIONS REQUIRED TO WAIT)  =
     A ',F5.1,T105,'MINS'/'0',10X,'AVERAGE TIME FROM CFF UNTIL FIRST SHO
     1T (MISSIONS NOT REQUIRED TO WAIT)  =  ',F5.1,T93,'MINS'/'0',10X,'A
     2VERAGE TIME FROM CFF UNTIL FIRST SHOT (ALL MISSIONS)  =  ',F5.1,
     3T76,'MINS'/'0',10X,'MAXIMUM TIME FROM CFF UNTIL FIRST SHOT  =  ',
     4I4,T60,'MINS'///'0',10X,'AVERAGE TRAVEL TIME  =  ',F5.1,T42,'MINS'
     5/'0',10X,'AVERAGE FIRING TIME  =  ',F5.1,T42,'MINS'/'0',10X,'AVERA
     6GE TOTAL SERVICE TIME (TRAVEL + SETUP + FIRING TIME)  =  ',F5.1,
     7T80,'MINS'/////)
      WRITE(W,5250) XUTILZ
 5250 FORMAT('0',T16,'*** SHIP UTILIZATION STATISTICS ***'///' ',10X,'OV
     1ERALL SHIP UTILIZATION  =  ',F5.2///' ',T12,'SHIP NR',T24,'8"/55',
     2T34,'6"/47',T44,'5"/54',T54,'5"/38'//)
      DO 5350 I=1,MAXNR
      WRITE(W,5300) I,XUT855(I),XUT647(I),XUT554(I),XUT538(I)
 5300 FORMAT(' ',14X,I1,8X,F4.2,6X,F4.2,6X,F4.2,6X,F4.2)
 5350 CONTINUE
      WRITE(W,5400) XUTL85,XUTL64,XUTL55,XUTL53
 5400 FORMAT('0',T14,'ALL',8X,F4.2,6X,F4.2,6X,F4.2,6X,F4.2)
      IF(REPPOL.EQ.1) GO TO 5575
      WRITE(W,5450)
 5450 FORMAT('1',T27,'*** REPLENISHMENT STATISTICS ***'///' ',T12,'TIMES
     1 INDICATED BELOW ARE TOTAL MINUTES OFF STATION FOR REPLENISHMENT F
     2OR EACH SHIP'///' ',T12,'SHIP NR',T29,'8"/55',T48,'6"/47',T67,'5"/
     354',T86,'5"/38'//' ',T24,'REFUEL   REARM      REFUEL   REARM      RE
     4FUEL   REARM      REFUEL   REARM'//)
      DO 5500 I=1,MAXNR
      WRITE(W,5475) I,FUELTM(I,1),ARMTIM(I,1),FUELTM(I,2),ARMTIM(I,2),
     1              FUELTM(I,3),ARMTIM(I,3),FUELTM(I,4),ARMTIM(I,4)
 5475 FORMAT(' ',13X,I1,8X,I5,3X,I5,6X,I5,3X,I5,6X,I5,3X,I5,6X,I5,3X,I5)
 5500 CONTINUE
 5575 WRITE(W,5600)
 5600 FORMAT('0',5X,'     '/////' ',T27,'*** AMMUNITION EXPENDITURES ***'//
     1' ',T12,'FIGURES BELOW ARE TOTAL ROUNDS EXPENDED BY EACH SHIP'//
     2' ',T12,'SHIP NR',T26,'8"/55',T39,'6"/47',T52,'5"/54',T65,'5"/38'/
     3/)
      DO 5700 I=1,MAXNR
      WRITE(W,5650) I,TOTAMX(I,1),TOTAMX(I,2),TOTAMX(I,3),TOTAMX(I,4)
 5650 FORMAT(' ',13X,I1,8X,I7,6X,I7,6X,I7,6X,I7)
 5700 CONTINUE
C
C     THIS ITERATION IS COMPLETE
 5110 CONTINUE
```

```
C     *******************************************************************
C
C     THE PROBLEM IS COMPLETE.  CALCULATE OVERALL STATISTICAL RESULTS
C
C
      XMULT = 1.0/(NRIT-1.0)
      XAVGWT = XOAVWT/NRIT
      XWTVAR = XMULT * (XWTSQR - XAVGWT*XOAVWT)/NRIT
      XWTDEV = SQRT(XWTVAR)
      YAVGWT = YOAVWT/NRIT
      YWTVAR = XMULT * (YWTSQR - YAVGWT*YOAVWT)/NRIT
      YWTDEV = SQRT(YWTVAR)
      XAVFST = XOAVFS/NRIT
      XFSVAR = XMULT * (XFSSQR - XAVFST*XOAVFS)/NRIT
      XFSDEV = SQRT(XFSVAR)
      YAVFST = YOAVFS/NRIT
      YFSVAR = XMULT * (YFSSQR - YAVFST*YOAVFS)/NRIT
      YFSDEV = SQRT(YFSVAR)
      ZAVFST = ZOAVFS/NRIT
      ZFSVAR = XMULT * (ZFSSQR - ZAVFST*ZOAVFS)/NRIT
      ZFSDEV = SQRT(ZFSVAR)
      XAVGQ = XOAVGQ/NRIT
      XQVAR = XMULT * (XAVQSQ - XAVGQ*XOAVGQ)/NRIT
      XQDEV = SQRT(XQVAR)
      XAVSVC = XOAVSV/NRIT
      XSVVAR = XMULT * (XSVSQR - XAVSVC*XOAVSV)/NRIT
      XSVDEV = SQRT(XSVVAR)
      XAVTRV = XOAVTR/NRIT
      XTRVAR = XMULT* (XTRSQR - XAVTRV*XOAVTR)/NRIT
      XTRDEV = SQRT(XTRVAR)
      XAVFIR = XOAVFR/NRIT
      XFRVAR = XMULT * (XFRSQR - XAVFIR*XOAVFR)/NRIT
      XFRDEV = SQRT(XFRVAR)
      XPERWT = XOPRWT/NRIT
      XPERVR = XMULT * (XPERSQ - (XOPRWT**2)/NRIT)
      XPERDV = SQRT(XPERVR)
      IF(NR855.EQ.0) GO TO 6020
      DO 6010 IK=1,NR855
      FUELTM(IK,1) = OFULTM(IK,1)/NRIT
      ARMTIM(IK,1) = OARMTM(IK,1)/NRIT
      TOTAMX(IK,1) = OAMMEX(IK,1)/NRIT
      XUT855(IK) = XOT855(IK)/NRIT
      X85VAR(IK) = XMULT * (X85SQR(IK) - XUT855(IK)*XOT855(IK))/NRIT
 6010 X85DEV(IK) = SQRT(X85VAR(IK))
      XUTL85 = XOTL85/NRIT
      XU85VR = XMULT * (XU85SQ - XUTL85*XOTL85)/NRIT
      XU85DV = SQRT(XU85VR)
 6020 IF(NR647.EQ.0) GO TO 6040
```

```
      DO 6030 IK=1,NR647
      FUELTM(IK,2) = QFULTM(IK,2)/NRIT
      ARMTIM(IK,2) = QARMTM(IK,2)/NRIT
      TOTAMX(IK,2) = QAMMEX(IK,2)/NRIT
      XUT647(IK) = XOT647(IK)/NRIT
      X64VAR(IK) = XMULT * (X64SQR(IK) - XUT647(IK)*XOT647(IK))/NRIT
 6030 X64DEV(IK) = SQRT(X64VAR(IK))
      XUTL64 = XOTL64/NRIT
      XU64VR = XMULT * (XU64SQ - XUTL64*XOTL64)/NRIT
      XU64DV = SQRT(XU64VR)
 6040 IF(NR554.EQ.0) GO TO 6060
      DO 6050 IK=1,NR554
      FUELTM(IK,3) = QFULTM(IK,3)/NRIT
      ARMTIM(IK,3) = QARMTM(IK,3)/NRIT
      TOTAMX(IK,3) = QAMMEX(IK,3)/NRIT
      XUT554(IK) = XOT554(IK)/NRIT
      X55VAR(IK) = XMULT * (X55SQR(IK) - XUT554(IK)*XOT554(IK))/NRIT
 6050 X55DEV(IK) = SQRT(X55VAR(IK))
      XUTL55 = XOTL55/NRIT
      XU55VR = XMULT * (XU55SQ - XUTL55*XOTL55)/NRIT
      XU55DV = SQRT(XU55VR)
 6060 IF(NR538.EQ.0) GO TO 6080
      DO 6070 IK=1,NR538
      FUELTM(IK,4) = QFULTM(IK,4)/NRIT
      ARMTIM(IK,4) = QARMTM(IK,4)/NRIT
      TOTAMX(IK,4) = QAMMEX(IK,4)/NRIT
      XUT538(IK) = XOT538(IK)/NRIT
      X53VAR(IK) = XMULT * (X53SQR(IK) - XUT538(IK)*XOT538(IK))/NRIT
 6070 X53DEV(IK) = SQRT(X53VAR(IK))
      XUTL53 = XOTL53/NRIT
      XU53VR = XMULT * (XU53SQ - XUTL53*XOTL53)/NRIT
      XU53DV = SQRT(XU53VR)
 6080 XUTILZ = XOUTIL/NRIT
      XUTVAR = XMULT * (XUTSQR - XUTILZ*XOUTIL)/NRIT
      XUTDEV = SQRT(XUTVAR)
      MAXFST = OMXFST/NRIT
      XVARFS  = XMULT * (FSTSQR - (OMXFST**2)/NRIT)/NRIT
      XDEVFS = SQRT(XVARFS)
      MAXINO = OMXINO/NRIT
      IF(MOD(OMXINO,NRIT).GT.(NRIT/2)) MAXINO = MAXINO + 1
      XVARMX = XMULT * (MXOSQR - (OMXINO**2)/NRIT)/NRIT
      XDEVMX = SQRT(XVARMX)
      TOTO = OTOTO/NRIT
      IF(MOD(OTOTO,NRIT).GT.(NRIT/2)) TOTO = TOTO + 1
      XVARTO = XMULT * (TOOSQR - (OTOTO**2)/NRIT)/NRIT
      XDEVTO = SQRT(XVARTO)
      XCLOCK = XOCLK/NRIT
      XCLKVR = XMULT * (XCLKSQ - XCLOCK*XOCLK)/NRIT
```

```
      XCLKDV = SQRT(XCLKVR)
      TOTMSN = OTOTMS/NRIT
      IF(MOD(OTOTMS,NRIT).GT.NRIT/2) TOTMSN = TOTMSN+ 1
      XVARMS = XMULT * (TOMSSQ - (OTOTMS**2)/NRIT)/NRIT
      DEVMS = IFIX(SQRT(XVARMS) + 0.5)
      MAXQTM = OMXQTM/NRIT
      IF(MOD(OMXQTM,NRIT).GT.(NRIT/2)) MAXQTM = MAXQTM + 1
      XVARQT = XMULT * (QTMSQR - (OMXQTM**2)/NRIT)/NRIT
      DEVQT = IFIX(SQRT(XVARQT) + 0.5)
C
C
C          *** PRINT OUT RESULTS ***
C
C
      WRITE(W,8000) NRIT
 8000 FORMAT('1',T25,'****** OVERALL STATISTICAL RESULTS ******'///' ',
     1T11,'TABULATED BELOW ARE THE MEAN AND THE STANDARD DEVIATION OF TH
     2E MEAN'/' ',T11,'OF THE INDICATED QUANTITIES AS COMPUTED FOR ',
     3I3,1X,'ITERATIONS'/' ',T11,'OF THE PROBLEM'////' ',T18,'QUANTITY',
     4T65,'MEAN',T74,'STD DEV'//)
      WRITE(W,8010) XCLOCK,XCLKDV,TOTMSN,DEVMS
 8010 FORMAT(' ',T11,'TOTAL PROBLEM TIME (DAYS)',T63,F6.2,5X,F6.2//' ',
     1T11,'TOTAL NUMBER OF MISSIONS FIRED',T63,I6,5X,I6///)
      WRITE(W,8020) XAVGWT,XWTDEV,YAVGWT,YWTDEV,MAXQTM,DEVQT
 8020 FORMAT('0',T11,'AVERAGE WAITING TIME PER MISSION (INCL ONLY',T63,
     1F6.1,5X,F6.2/' ',T16,'MISSIONS WHICH WERE REQUIRED TO WAIT) (MINS)
     2'//' ',T11,'AVERAGE WAITING TIME PER MISSION (ALL MISSIONS)',T63,
     3F6.1,5X,F6.2//' ',T11,'MAXIMUM WAITING TIME (MINS)',T63,I6,5X,I6//
     4/)
      WRITE(W,8030) XAVGQ,XQDEV,MAXINQ,XDEVMX,TOTQ,XDEVTQ,XPERWT,XPERDV
 8030 FORMAT('0',T11,'AVERAGE NUMBER OF MISSIONS AWAITING ASSIGNMENT',
     1T63,F6.2,5X,F6.2//' ',T11,'MAXIMUM NUMBER OF MISSIONS AWAITING ASS
     2IGNMENT',T63,I6,5X,F6.2//' ',T11,'TOTAL NUMBER OF MISSIONS WHICH W
     3ERE REQUIRED',T63,I6,5X,F6.2/' ',T16,'TO WAIT FOR ASSIGNMENT'//' '
     4,T11,'PERCENT OF MISSIONS WHICH WERE REQUIRED TO WAIT',T63,F6.1,5X
     5,F6.2/' ',T16,'FOR ASSIGNMENT'///)
      WRITE(W,8040) YAVFST,YFSDEV,XAVFST,XFSDEV
 8040 FORMAT('0',T11,'AVERAGE TIME FROM CALL FOR FIRE (CFF) UNTIL FIRST'
     1,T63,F6.1,5X,F6.2/' ',T16,'SHOT (INCL ONLY MISSIONS REQUIRED TO WA
     2IT)'//' ',T11,'AVERAGE TIME FROM CFF UNTIL FIRST SHOT (INCL ONLY',
     3T63,F6.1,5X,F6.2/' ',T16,'MISSIONS NOT REQUIRED TO WAIT)'/)
      WRITE(W,8045) ZAVFST,ZFSDEV,MAXFST,XDEVFS
 8045 FORMAT(' ',T11,'AVERAGE TIME FROM CFF UNTIL FIRST SHOT',T63,F6.1,
     15X,F6.2/' ',T16,'(ALL MISSIONS)'//' ',T11,'MAXIMUM TIME FROM CFF U
     2NTIL FIRST SHOT',T63,I5,5X,F6.1///)
      WRITE(W,8050) XAVTRV,XTRDEV,XAVFIR,XFRDEV,XAVSVC,XSVDEV
 8050 FORMAT('0',T11,'AVERAGE TRAVEL TIME (MINS)',T63,F6.1,5X,F6.2//' ',
     1T11,'AVERAGE FIRING TIME',T63,F6.1,5X,F6.2//' ',T11,'AVERAGE TOTAL
```

```
     2 SERVICE TIME',T63,F6.1,5X,F6.2/' ',T16,'(TRAVEL + SETUP + FIRING
     3TIME)')
      WRITE(W,9000) XUTILZ,XUTDEV
 9000 FORMAT('1',T24,'** SHIP UTILIZATION STATISTICS **'///' ',T11,'OVER
     1ALL SHIP UTILIZATION :  MEAN = ',F5.3,T51,', STD DEV = ',F5.3///)
      WRITE(W,9010)
 9010 FORMAT(' ',T11,'(VALUES IN BELOW TABLE ARE THE MEAN ON TOP'/' ',
     1T12,'WITH STANDARD DEVIATION BELOW)'///' ',T11,'SHIP NR',T27,'8"/5
     25',T38,'6"/47',T49,'5"/54',T60,'5"/38'//)
      DO 9030 I=1,MAXNS
      WRITE(W,9020) I,XUT855(I),XUT647(I),XUT554(I),XUT538(I),
     1              X85DEV(I),X64DEV(I),X55DEV(I),X53DEV(I)
 9020 FORMAT(' ',13X,I1,11X,F5.3,6X,F5.3,6X,F5.3,6X,F5.3/' ',25X,F5.3,
     16X,F5.3,6X,F5.3,6X,F5.3//)
 9030 CONTINUE
      WRITE(W,9040) XUTL85,XUTL64,XUTL55,XUTL53,
     1              XU85DV,XU64DV,XU55DV,XU53DV
 9040 FORMAT(' ',T13,'ALL',T27,F5.3,6X,F5.3,6X,F5.3,6X,F5.3/' ',T27,F5.3
     1,6X,F5.3,6X,F5.3,6X,F5.3)
      WRITE(W,8060)
 8060 FORMAT('1',T25,'** REPLENISHMENT STATISTICS **'///' ',T11,'VALUES
     1IN TABLE BELOW ARE MEAN TOTAL MINUTES OFF STATION FOR EACH SHIP'//
     2/)
      WRITE(W,8065)
 8065 FORMAT(' ',T11,'SHIP NR',T26,'8"/55',T45,'6"/47',T64,'5"/54',T83,
     1'5"/38'//' ',T21,'REFUEL   REARM      REFUEL   REARM      REFUEL   R
     2EARM      REFUEL   REARM'/)
      DO 8075 I=1,MAXNP
      WRITE(W,8070) I,FUELTM(I,1),ARMTIM(I,1),FUELTM(I,2),ARMTIM(I,2),
     1              FUELTM(I,3),ARMTIM(I,3),FUELTM(I,4),ARMTIM(I,4)
 8070 FORMAT('0',14X,I1,4X,I5,3X,I5,6X,I5,3X,I5,6X,I5,3X,I5,6X,I5,3X,I5)
 8075 CONTINUE
      WRITE(W,8080)
 8080 FORMAT(' ',5X,'  '/////' ',T25,'** AMMUNITION EXPENDITURES **'///
     1' ',T11,'VALUES IN BELOW TABLE ARE MEAN TOTAL ROUNDS EXPENDED BY E
     2ACH SHIP'///)
      WRITE(W,8085)
 8085 FORMAT(' ',T11,'SHIP NR',T28,'8"/55',T39,'6"/47',T50,'5"/54',T61,
     1'5"/38'/)
      DO 8095 I=1,MAXNP
      WRITE(W,8090) I,TOTAMX(I,1),TOTAMX(I,2),TOTAMX(I,3),TOTAMX(I,4)
 8090 FORMAT('0',14X,I1,9X,I7,4X,I7,4X,I7,4X,I7)
 8095 CONTINUE
      GO TO 9999
 9900 WRITE(W,9905) AREA(I)
 9905 FORMAT('0',T15,'A TYPE 8 MISSION HAS OCCURRED IN AREA ',I2)
 9999 STOP
      END
```

```
      SUBROUTINE VENTCH(VENT,A,EVM,REP)
C
C
C     THIS SUBROUTINE DETERMINES THE CHRONOLOGICAL POSITION OF EACH NEW
C     EVENT ON THE EVENT CHAIN, PLACES THE NEW EVENT IN THAT POSITION,
C     AND MOVES ALL LATER EVENTS BACK ONE POSITION ON THE EVENT CHAIN
C
      IMPLICIT INTEGER(A-W)
      COMMON NRVENT,K,KOUNT,IR11,IR12,IR13,KR,MINSET,MAXSET,SPEED,
     1       TRAVEL(1000),SERVC(1000),FIRE(1000),[illegible](1000),
     2       AMMEXP(1000),EVENT(2300),EVTYP(2300),[illegible]MSN(2300),
     3       REPSHP(2300),VAIL(36),STATUS(9,4),FIR[illegible](4,4),DENOM(4,4),
     4       MINAMM(4,4),MAXAMM(4,4)
      UPCOME = K + 1
      DO 2100 JJ=UPCOME,NRVENT
      IF(VENT.GT.EVENT(JJ)) GO TO 2100
      NV = NRVENT - JJ + 1
      DO 2050 JK=1,NV
      JKK = NRVENT - JK + 1
      EVENT(JKK+1) = EVENT(JKK)
      EVTYP(JKK+1) = EVTYP(JKK)
      EVTMSN(JKK+1) = EVTMSN(JKK)
      REPSHP(JKK+1) = REPSHP(JKK)
 2050 CONTINUE
      JJJ = JJ
      GO TO 2150
 2100 CONTINUE
      JJJ = NRVENT + 1
 2150 EVENT(JJJ) = VENT
      EVTYP(JJJ) = A
      EVTMSN(JJJ) = EVM
      REPSHP(JJJ) = REP
      NRVENT = NRVENT + 1
      RETURN
      END
```

```
      SUBROUTINE SERVIC(SHIP.TARTYP,RNG,II,DIS)
C
C
C     THIS SURROUTINE CALCULATES THE TOTAL SERVICE TIME AND AMMUNITION
C     EXPENDITURE FOR EACH MISSION
C
C
      IMPLICIT INTEGER(A-W)
      COMMON NRVENT,K,KOUNT,IR11,IR12,IR13,KR,MINSET,MAXSET,SPEED,
     1       TRAVEL(1000),SERVC(1000),FIRE(1000),SETUP(1000),
     2       AMMEXP(1000),EVENT(2300),EVTYP(2300),EVTMSN(2300),
     3       REPSHP(2300),VAIL(36),STATUS(9,4),FIRTIM(4,4),DENOM(4,4),
     4       MINAMM(4,4),MAXAMM(4,4)
C
C     CALCULATE THE MEAN OF THE EXPONENTIAL DISTRIBUTION OF FIRING TIMES
C     AND CALCULATE FIRING TIME FOR THIS MISSION
C
      MU = FIRTIM(SHIP,TARTYP) + RNG/DENOM(SHIP,TARTYP) + 0.5
      IR11 = IR11 * KR
      XRN = 0.5 + FLOAT(IR11) * 2.328306E-10
      FIRE(II) = -MU*ALOG(XRN) + 0.5
      IF(FIRE(II).LE.0.0) FIRE(II) = 1
C
C     CALCULATE TRAVEL TIME
C
      TRAVEL(II) = DIS/(SPEED*33.33) + 0.5
C
C     CALCULATE SETUP TIME
C
      IR12 = IR12 * KR
      XRN = 0.5 + FLOAT(IR12) * 2.328306E-10
      SETUP(II) = MINSET + XRN * (MAXSET - MINSET) + 0.5
C
C     CALCULATE TOTAL SERVICE TIME
C
      SERVC(II) = TRAVEL(II) + SETUP(II) + FIRE(II)
C
C     CALCULATE AMMUNITION EXPENDITURE
C
      IR13 = IR13 * KR
      XRN = 0.5 + FLOAT(IR13) * 2.328306E-10
      AMMEXP(II) = (MINAMM(SHIP,TARTYP) + XRN * (MAXAMM(SHIP,TARTYP) -
     1             MINAMM(SHIP.TARTYP))) * FIRE(II)
      RETURN
      END
```

```
      SUBROUTINE AVAIL(NRSHIP,SHPTYP)
C
C
C     THIS SUBROUTINE CHECKS THE AVAILABILITY OF ALL SHIPS OF A TYPE
C     APPROPRIATE TO FIRE THE MISSION UNDER CONSIDERATION, AND PLACES ALL
C     AVAILABLE SHIPS (STATUS = 1) INTO THE VECTOR VAIL
C
      IMPLICIT INTEGER(A-W)
      COMMON NRVENT,K,KOUNT,IR11,IR12,IR13,KR,MINSET,MAXSET,SPEED,
     1       TRAVEL(1000),SERVC(1000),FIRE(1000),SETUP(1000),
     2       AMMEXP(1000),EVENT(2300),EVTYP(2300),EVTMSN(2300),
     3       REPSHP(2300),VAIL(36),STATUS(9,4),FIRTIM(4,4),DENOM(4,4),
     4       MINAMM(4,4),MAXAMM(4,4)
      DO 4100 JB=1,NRSHIP
      IF(STATUS(JB,SHPTYP).NE.1) GO TO 4100
      KOUNT = KOUNT + 1
      VAIL(KOUNT) = JB*10 + SHPTYP
 4100 CONTINUE
      RETURN
      END
```

APPENDIX C: PRINTOUT OF INPUT DATA FOR STDF FEASIBILITY STUDY
(For the Case When NR855 = NR554 = 1, NR538 = 0)

```
*** INPUT DATA ***

NUMBER OF 8"/55 SHIPS PRESENT = 1
NUMBER OF 6"/47 SHIPS PRESENT = 1
NUMBER OF 5"/54 SHIPS PRESENT = 1
NUMBER OF 5"/38 SHIPS PRESENT = 0

MAX RANGE OF 8"/55 GUN = 30000 YDS
MAX RANGE OF 6"/47 GUN = 21000 YDS
MAX RANGE OF 5"/54 GUN = 26000 YDS
MAX RANGE OF 5"/38 GUN = 15000 YDS

DISTANCE OF WESTERN EDGE OF WAITING PATTERN FROM Y-AXIS = 10000 YDS
DISTANCE OF NORTHERN EDGE OF WAITING PATTERN FROM GUNLINE =  5000 YDS
E-W LENGTH OF WAITING PATTERN = 20000 YDS
N-S LENGTH OF WAITING PATTERN =  5000 YDS

SPEED TO FIRING POSITION = 20 KNOTS
MIN SETUP TIME =  3 MINS
MAX SETUP TIME = 15 MINS

ASSIGNMENT DOCTRINE: 1
QUEUE DISCIPLINE: 2
REPLENISHMENT POLICY: 2
TYPE OF FUELING SCHEDULE USED: 2

      * COMPONENTS OF MEAN FIRING TIME *

MEAN FIRING TIME DUE TO TARGET TYPE:  (MINUTES FROM TABLE BELOW)
```

TYPE SHIP	TARGET TYPE 1	2	3	4
1	15	10	12	10
2	14	8	11	9
3	8	5	14	10
4	18	12	18	12

DENOMINATOR OF RANGE FACTOR: (FROM TABLE BELOW)

TYPE SHIP	TARGET TYPE 1	2	3	4
1	10000	8000	6000	6000
2	10000	8000	6000	6000
3	10000	8000	6000	6000
4	8000	4000	4000	4000

* AREA INFORMATION *

AREA NR	AREA BOUNDARIES NORTH	SOUTH	WEST	EAST	EXP PATROL DURATION MIN	MAX	EXP NR OF CFF	TARGET TYPE PROBABILITIES 1	2	3	4
1	25000	20000	0	4000	6.0	7.0	8.0	0.10	0.20	0.50	0.20
2	25000	20000	4000	8000	6.4	7.4	8.0	0.10	0.20	0.50	0.20
3	25000	20000	8000	12000	6.0	7.0	8.0	0.10	0.20	0.50	0.20
4	25000	20000	12000	16000	5.8	6.8	8.0	0.10	0.20	0.50	0.20
5	25000	20000	16000	19000	4.6	7.6	8.0	0.20	0.30	0.40	0.10
6	25000	20000	19000	22000	5.0	7.0	10.0	0.20	0.40	0.10	0.30
7	25000	20000	22000	28000	5.9	6.9	10.0	0.20	0.40	0.10	0.30
8	25000	20000	28000	40000	6.5	7.0	12.0	0.20	0.20	0.50	0.10
9	20000	15000	0	4000	6.5	7.5	12.0	0.10	0.15	0.65	0.10
10	20000	15000	4000	8000	5.7	6.7	11.0	0.10	0.20	0.50	0.20
11	20000	15000	8000	13000	6.2	7.2	12.0	0.10	0.20	0.50	0.20
12	20000	15000	13000	18000	5.0	6.5	15.0	0.10	0.10	0.60	0.20
13	20000	15000	18000	21000	4.5	7.5	18.0	0.25	0.25	0.35	0.15
14	20000	15000	21000	24000	5.3	7.3	15.0	0.20	0.40	0.10	0.30
15	20000	15000	24000	32000	6.5	7.5	15.0	0.20	0.40	0.10	0.30
16	20000	12000	32000	40000	6.6	6.8	15.0	0.10	0.15	0.40	0.35
17	15000	10000	0	4000	6.5	7.5	10.0	0.10	0.20	0.10	0.60
18	15000	10000	4000	8000	6.0	7.0	11.0	0.10	0.20	0.50	0.20
19	15000	12000	8000	13000	5.8	6.8	12.0	0.15	0.25	0.30	0.30
20	15000	12000	13000	18000	5.7	6.7	10.0	0.10	0.10	0.60	0.20
21	15000	12000	18000	22000	4.5	6.5	11.0	0.10	0.30	0.50	0.10
22	15000	12000	22000	26000	5.0	6.8	18.0	0.20	0.40	0.10	0.30
23	15000	12000	26000	32000	6.0	7.0	15.0	0.20	0.40	0.10	0.30
24	10000	6000	0	8000	6.0	7.0	12.0	0.20	0.30	0.25	0.25
25	12000	8000	8000	15000	6.2	7.2	8.0	0.05	0.35	0.20	0.40
26	12000	8000	15000	21000	5.5	7.0	10.0	0.10	0.25	0.35	0.30
27	12000	8000	21000	24000	4.0	7.0	11.0	0.20	0.40	0.20	0.20
28	12000	8000	24000	28000	4.5	7.5	22.0	0.20	0.40	0.10	0.30
29	12000	8000	28000	40000	6.4	6.6	18.0	0.20	0.40	0.10	0.30
30	8000	4000	8000	15000	6.2	7.2	7.0	0.10	0.20	0.10	0.60
31	8000	4000	15000	21000	5.0	6.5	7.0	0.05	0.35	0.20	0.40
32	8000	5000	21000	26000	4.0	7.5	8.0	0.20	0.50	0.10	0.20
33	8000	5000	26000	30000	4.0	7.0	18.0	0.40	0.30	0.20	0.10
34	8000	5000	30000	40000	6.3	6.5	23.0	0.40	0.30	0.20	0.10

* REFUELING AND REARMING DATA *

OFF-STATION TIME PARAMETERS:
(MINUTES OFF STATION PER EVOLUTION FROM TABLE BELOW)

CRUISERS				DESTROYERS			
REFUEL		REARM		REFUEL		REARM	
MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
150	180	240	300	120	150	180	240

INITIAL AMMUNITION LEVELS:
(ROUNDS ON BOARD FROM BELOW TABLE)

SHIP NR	SHIP TYPE 8"/55	6"/47	5"/54	5"/38
1	8000	10000	12000	6000

MINIMUM ALLOWED AMMUNITION LEVELS =

8"/55: 1000 RDS
6"/47: 1000 RDS
5"/54: 2000 RDS
5"/38: 1000 RDS

EXPECTED AMMUNITION EXPENDITURES:
(ROUNDS PER MINUTE PER MISSION)

TYPE SHIP	TARGET TYPE 1 MIN	1 MAX	2 MIN	2 MAX	3 MIN	3 MAX	4 MIN	4 MAX
1	4	10	3	9	2	8	2	8
2	4	11	3	10	2	8	2	6
3	6	22	5	20	5	18	5	18
4	4	10	3	9	3	10	3	10

APPENDIX D: PRINTOUT OF MISSION HISTORY FOR STDF FEASIBILITY STUDY - (FIRST ITERATION WITH INPUT PARAMETERS IAW APPENDIX C)

*** MISSION HISTORY ***

ITERATION NUMBER 1

MISSION NUMBER	AREA NUMBER	TARGET TYPE	MISSION TYPE	RANGE (YDS)	SHIP ASSIGNED TYPE	SHIP ASSIGNED NR	TIME OF CALL FOR FIRE (DTG)	TIME AWAITING ASSGNMT (MINS)	TRAVEL TIME (MINS)	TIME OF FIRST SHOT (MINS FROM CFF)	ACTUAL FIRING TIME (MINS)	TIME MISSION COMPLETED (DTG)
1	28	4	5	10997	2	1	10807	0	13	27	18	10852
2	13	3	6	19983	1	1	10922	0	9	22	10	10954
3	28	2	5	8939	2	1	11021	0	23	28	6	11055
4	16	4	6	15514	1	1	11031	0	22	26	5	11102
5	32	1	5	6566	3	1	11043	0	18	25	17	11125
6	25	2	5	8718	1	1	11128	0	23	37	3	11208
7	9	3	6	16886	3	1	11226	0	29	36	18	11320
8	2	3	7	23235	1	1	11306	0	32	37	16	11359
9	8	4	7	22436	1	1	11434	0	13	23	30	11527
10	11	3	6	15497	2	1	11530	0	17	26	11	11607
11	23	3	5	12631	3	1	11557	0	12	20	5	11622
12	6	2	7	21845	1	1	11607	0	16	20	11	11638
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281	26	2	5	11465	2	1	60506	0	20	33	8	60547
282	27	2	5	11559	1	1	60550	0	8	16	45	60651
283	22	1	5	13626	2	1	60554	0	10	15	16	60625
284	23	4	5	12730	3	1	60558	0	22	30	1	60629
285	11	4	6	17910	3	1	60640	0	6	11	5	60656
286	33	4	5	5899	2	1	60648	0	13	19	19	60726
287	8	4	7	22802	3	1	60715	0	21	27	1	60743
288	14	3	6	18324	1	1	60736	0	14	23	11	60810
289	22	4	5	14835	2	1	60742	0	23	35	6	60823
290	13	4	6	18436	3	1	60833	0	9	13	29	60915
291	23	2	5	13852	1	1	60835	0	10	21	8	60904
292	11	1	6	17594	2	1	60913	0	14	23	3	60939
293	21	1	5	13667	3	1	60948	0	10	24	2	61014
294	33	2	5	6994	1	1	60958	0	24	35	13	61046
295	18	3	5	14936	2	1	61015	0	34	46	8	61109
296	24	2	5	9761	3	1	61027	0	40	53	2	61122

297	30	2	5	7021	1	1	61100	0	11	16	3	61119
298	14	4	6	15348	2	1	61109	0	18	21	8	61136
299	30	2	5	6478	3	1	61126	0	19	33	4	61203
300	24	4	5	6360	2	1	61128	10	32	47	14	61229
301	18	2	5	14822	2	1	61243	0	24	30	6	61319
302	16	1	6	19806	2	1	61332	0	14	24	6	61402
303	18	3	5	10867	3	1	61339	0	13	21	6	61406
304	8	3	7	21295	1	1	61452	0	8	16	4	61512
305	27	1	5	11969	1	1	61518	0	13	22	6	61546
306	10	3	6	18115	1	1	61548	0	10	18	25	61631
307	27	2	5	11226	3	1	61630	0	21	35	1	61706
308	24	3	5	6928	1	1	61913	0	15	23	12	61948
309	27	3	5	8527	2	1	62025	0	8	18	5	62048
310	28	4	5	10810	3	1	62109	0	11	17	5	62131
311	25	3	5	8118	3	1	62152	0	8	15	8	62215
312	12	2	6	19265	1	1	62234	0	9	23	2	62259
313	10	3	6	19259	1	1	62301	0	23	36	1	62338
314	27	1	5	9737	2	1	70002	0	12	22	39	70103
315	25	2	5	11756	1	1	70013	0	9	23	3	70039
316	23	4	5	14176	1	1	70042	0	12	18	56	70156
317	22	2	5	14702	2	1	70119	0	21	25	14	70158
318	9	3	6	19375	3	1	70123	0	39	51	35	70249
319	16	4	5	13152	1	1	70151	5	16	31	1	70223
320	25	1	5	11951	2	1	70203	0	12	21	11	70235
321	27	2	5	10524	1	1	70237	0	14	27	7	70311
322	31	3	5	7582	1	1	70333	0	16	21	5	70359
323	19	4	5	14080	2	1	70433	0	11	21	12	70506
324	15	1	6	15501	3	1	70503	0	22	37	23	70603
325	10	2	6	16804	1	1	70514	0	22	37	11	70602
326	28	2	5	9046	2	1	70546	0	17	31	2	70619
327	7	3	7	21612	1	1	70554	8	26	46	1	70641
328	10	2	6	17903	3	1	70603	0	36	40	2	70645
329	28	1	5	10323	1	1	70656	0	9	21	31	70748
330	8	3	7	21295	3	1	70720	0	23	34	4	70758
331	11	3	6	16633	2	1	70724	0	13	27	8	70759
332	17	3	5	13137	2	1	70802	0	22	30	1	70833
333	5	1	7	24122	3	1	70835	0	13	21	1	70857
334	10	3	6	16497	1	1	70918	0	26	40	34	71032
335	27	4	5	9507	3	1	71044	0	16	20	4	71108
336	28	2	5	10266	1	1	71103	0	8	21	6	71130
337	7	2	6	20035	2	1	71125	0	10	21	2	71148
338	16	4	6	19537	1	1	71221	0	14	22	1	71244
339	31	3	5	6360	3	1	71238	0	13	20	28	71326
340	22	4	5	12182	2	1	71243	0	16	22	6	71311
341	3	3	6	20267	1	1	71304	0	29	37	1	71342
342	8	3	7	23871	3	1	71325	1	17	27	4	71356
343	27	4	5	8656	1	1	71425	0	15	19	1	71445
344	23	1	5	12049	2	1	71439	0	26	31	20	71530
345	34	1	5	6864	1	1	71530	0	16	23	13	71606
346	7	1	7	22906	3	1	71600	0	20	27	19	71646
347	23	1	5	14680	2	1	[illegible]	0	17	21	44	71710
348	15	3	6	15647	2	1	[illegible]	0	15	26	1	71920
349	18	1	5	13679	3	1	71936	0	17	30	14	72020
350	28	2	5	8998	2	1	72034	0	18	26	2	72102
351	4	1	7	24375	1	1	72117	0	13	27	9	72153
352	2	2	6	20017	3	1	72117	0	26	37	3	72157
353	27	4	5	8579	2	1	72313	0	9	22	4	72339
354	26	4	5	11348	2	1	80054	0	18	26	21	80121
355	5	2	7	23595	1	1	80145	0	19	31	5	80221
356	10	1	6	18903	2	1	80416	0	20	30	1	80447
357	30	4	5	4848	3	1	80900	0	16	22	3	80925
358	27	2	5	8989	2	1	80939	0	9	13	3	80955

APPENDIX E: ITERATION STATISTICAL RESULTS FOR STDF FEASIBILITY STUDY - (FIRST ITERATION WITH INPUT PARAMETERS IAW APPENDIX C)

```
**** STATISTICAL RESULTS ****
     ITERATION NUMBER   1

TOTAL PROBLEM TIME  =   7 DAYS,  4 HOURS. 55 MINUTES
TOTAL NUMBER OF MISSIONS FIRED  =   358

AVERAGE WAITING TIME (INCL ONLY MISSIONS REQUIRED TO WAIT)  =   16.0 MINS
AVERAGE WAITING TIME (ALL MISSIONS)  =    3.9 MINS
MAXIMUM WAITING TIME  =    84 MINS

AVERAGE NUMBER OF MISSIONS AWAITING ASSIGNMENT  =   0.13
MAXIMUM NUMBER OF MISSIONS AWAITING ASSIGNMENT  =    5
TOTAL NUMBER OF MISSIONS WHICH WERE REQUIRED TO WAIT FOR ASSIGNMENT  =   86
PERCENT OF MISSIONS WHICH WERE REQUIRED TO WAIT FOR ASSIGNMENT  = 24.0

AVERAGE TIME FROM CALL FOR FIRE (CFF) UNTIL FIRST SHOT (MISSIONS REQUIRED TO WAIT)  =   40.2 MINS
AVERAGE TIME FROM CFF UNTIL FIRST SHOT (MISSIONS NOT REQUIRED TO WAIT)  =   25.7 MINS
AVERAGE TIME FROM CFF UNTIL FIRST SHOT (ALL MISSIONS)  =   29.2 MINS
MAXIMUM TIME FROM CFF UNTIL FIRST SHOT  =   119 MINS

AVERAGE TRAVEL TIME  =   16.3 MINS
AVERAGE FIRING TIME  =   11.9 MINS
AVERAGE TOTAL SERVICE TIME (TRAVEL + SETUP + FIRING TIME)  =   37.2 MINS
```

*** SHIP UTILIZATION STATISTICS ***

OVERALL SHIP UTILIZATION = 0.44

SHIP NR	8"/55	6"/47	5"/54	5"/38
1	0.50	0.41	0.42	0.0
ALL	0.50	0.41	0.42	0.0

*** REPLENISHMENT STATISTICS ***

TIMES INDICATED BELOW ARE TOTAL MINUTES OFF STATION FOR REPLENISHMENT FOR EACH SHIP

SHIP NR	8"/55		6"/47		5"/54		5"/38	
	REFUEL	REARM	REFUEL	REARM	REFUEL	REARM	REFUEL	REARM
1	164	288	155	0	133	199	0	0

*** AMMUNITION EXPENDITURES ***

FIGURES BELOW ARE TOTAL ROUNDS EXPENDED BY EACH SHIP

SHIP NR	8"/55	6"/47	5"/54	5"/38
1	9931	8418	14260	0

APPENDIX F: PRINTOUT OF OVERALL STATISTICAL RESULTS FOR STDF FEASIBILITY STUDY (WITH INPUT PARAMETERS IAW APPENDIX C)

****** OVERALL STATISTICAL RESULTS ******

TABULATED BELOW ARE THE MEAN AND THE STANDARD DEVIATION OF THE MEAN OF THE INDICATED QUANTITIES AS COMPUTED FOR 10 ITERATIONS OF THE PROBLEM

QUANTITY	MEAN	STD DEV
TOTAL PROBLEM TIME (DAYS)	7.34	0.04
TOTAL NUMBER OF MISSIONS FIRED	385	7
AVERAGE WAITING TIME PER MISSION (INCL ONLY MISSIONS WHICH WERE REQUIRED TO WAIT) (MINS)	19.9	1.78
AVERAGE WAITING TIME PER MISSION (ALL MISSIONS)	5.0	0.71
MAXIMUM WAITING TIME (MINS)	95	14
AVERAGE NUMBER OF MISSIONS AWAITING ASSIGNMENT	0.18	0.03
MAXIMUM NUMBER OF MISSIONS AWAITING ASSIGNMENT	5	0.54
TOTAL NUMBER OF MISSIONS WHICH WERE REQUIRED TO WAIT FOR ASSIGNMENT	95	6.71
PERCENT OF MISSIONS WHICH WERE REQUIRED TO WAIT FOR ASSIGNMENT	24.4	4.55
AVERAGE TIME FROM CALL FOR FIRE (CFF) UNTIL FIRST SHOT (INCL ONLY MISSIONS REQUIRED TO WAIT)	45.4	2.12
AVERAGE TIME FROM CFF UNTIL FIRST SHOT (INCL ONLY MISSIONS NOT REQUIRED TO WAIT)	25.7	0.07
AVERAGE TIME FROM CFF UNTIL FIRST SHOT (ALL MISSIONS)	30.6	0.78
MAXIMUM TIME FROM CFF UNTIL FIRST SHOT	132	13.5
AVERAGE TRAVEL TIME (MINS)	16.6	0.13
AVERAGE FIRING TIME	11.8	0.27
AVERAGE TOTAL SERVICE TIME (TRAVEL + SETUP + FIRING TIME)	37.4	0.35

** SHIP UTILIZATION STATISTICS **

OVERALL SHIP UTILIZATION : MEAN = 0.469, STD DEV = 0.007

(VALUES IN BELOW TABLE ARE THE MEAN ON TOP
WITH STANDARD DEVIATION BELOW)

SHIP NR	8"/55	6"/47	5"/54	5"/38
1	0.483 0.009	0.447 0.011	0.479 0.010	0.0 0.0
ALL	0.483 0.009	0.447 0.011	0.479 0.010	0.0 0.0

** REPLENISHMENT STATISTICS **

VALUES IN TABLE BELOW ARE MEAN TOTAL MINUTES OFF STATION FOR EACH SHIP

SHIP NR	8"/55		6"/47		5"/54		5"/38	
	REFUEL	REARM	REFUEL	REARM	REFUEL	REARM	REFUEL	REARM
1	158	275	165	97	130	206	0	0

** AMMUNITION EXPENDITURES **

VALUES IN BELOW TABLE ARE MEAN TOTAL ROUNDS EXPENDED BY EACH SHIP

SHIP NR	8"/55	6"/47	5"/54	5"/38
1	9270	8391	17133	0

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