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VECTORED INTERCEPT MODEL (VIM)-AN OPEN OCEAN SUBMARINE VERSUS SUBMARINE SEARCH AND DETECTION SIMULATION

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Monterey, California

December 1972

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

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Search and Detection Simulation

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ABSTRACT

A simulation model for the open ocean submarine versus submarine search and detection problem is presented. The objective of the simulation is to estimate the probability with which a nuclear powered attack submarine will achieve sonar detection of a nuclear powered transiting submarine using a search plan based on external intelligence. A detailed description of the model and its use are included along with a typical analysis.

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I. INTRODUCTION

This thesis contains a detailed description of the VECTORED INTERCEPT MODEL (VIM), an event sequenced Monte Carlo simulation of a submarine versus submarine open ocean search and detection problem assisted by external intelligence. The objective of VIM is to estimate the probability with which a nuclear powered attack submarine will achieve a direct path sonar detection of a nuclear powered target submarine based on a given geographical and tactical situation. The method used is to estimate the probability of detection at various times throughout the trial, combine the estimates to form a cumulative trial probability, then average over all trials. The method of estimation is explained in detail in Chapter III, Section A.

VIM was initially developed to determine the probability of an attack submarine establishing direct path sonar contact of a target submarine as a result of receiving intelligence provided by a shore based detection system for an analysis of the U.S. strategic defense plan by the Joint Chiefs of Staff War Gaming Agency (JWGA) [1]. In response to an interest expressed by Commander, Submarine Development Group II, VIM was extended into a more general form to be used in planning of exercises, extension of exercise results, and paremetric studies of the open ocean search and detection system. No reports of use of VIM by Submarine Development Group II have been published.

The twofold purpose of this thesis is to provide a detailed description of VIM including instructions in use of the model and to illustrate its use by means of an example. Chapter I is intended to acquaint the reader with the nature of the simulation and general format of the situation being modelled.

Chapter II will assist the reader in understanding the operation of VIM and determining if it is suitable for use in the analysis of his problem.

Chapter III contains the details of the simulation including the alternatives available to the user in relating the model to a specific problem. A description of the overall logic flow and each of the subprograms is included.

Chapter IV describes the input and output mechanisms of VIM including the various options designed to simplify data input and display, and an explanation of output messages.

Chapter V is a user's manual which includes the definitions of all input parameters and the keypunch instructions for constructing the input data deck. The user's manual is cross-referenced to the descriptive passages in the thesis which pertain to the inputs, and to the definitions of related inputs.

Chapter VI is a discussion of the methodology and data requirements for the execution of a simulation experiment using VIM, and an example of a problem to which VIM was applied.

Appendix A describes a method of utilizing layer depth information in an experiment. Appendix B is a program listing.

A. PROGRAM INFORMATION

VIM is written in FORTRAN IV for the IBM system 360 computer. The program space requirements are 120,000 bytes for storage and execution. No plotting, card punching or special tape drives are employed. Execution time varies between 0.15 seconds and 2.5 seconds per trial depending on the period of simulation and the level of output detail.

II. MODEL DESCRIPTION

This chapter includes a brief description of the simulation, an introduction to the terms which will be used throughout the thesis, and a discussion of the categories of input data. It is intended that within this chapter the reader will be able to assess the applicability of VIM to his problem.

A. MODEL STRUCTURE

In simulating the situation outlined in Chapter I, an attempt was made to maintain simplicity while permitting sufficient flexibility so that a wide variety of problems could be addressed. The following is a brief synopsis in terms of ships, playing area, ship motion, intelligence, detection and convergence zones of the method by which VIM portrays the basic scenario.

Ships: Two nuclear submarines are considered. An attack submarine is assigned the mission of intercepting and establishing close sonar contact within weapon range of a target submarine. The mission of the target is to complete an assigned transit undetected by the attack submarine. It must be noted that at no time during the simulation does the attacker actually establish close contact. Rather, the probability of the event is estimated at well defined times throughout each trial.

Playing area: The geography of the open ocean is approximated by a plane surface of unlimited dimension, and with a coordinate system centered at the attacker initial position. Ship positions are recorded in terms of miles east or west of the origin (X coordinate), and miles north or south of the origin (Y coordinate). Operating depths are not modelled in VIM, however a method of accounting for layer depths is presented in Appendix A.

Ship motion: The attacker is initially assigned to a waiting station where it will remain until it receives intelligence on the target. This intelligence is received either through its own sensors or via a communications link with a surveillance facility. Upon receipt of the intelligence the attacker attempts to establish sonar contact by transitting to a point believed to be ahead of the target and then executing a search pattern about that point. The attacker remains at the search station until new intelligence is received.

Basic target motion is an input to the simulation. The target will deviate from its track in a random manner if desired, and will also execute an evasion pattern if a counterdetection occurs, returning to the track upon completion of the evasion maneuver.

Intellignece: Information concerning the target upon which the attacker bases its search pattern may be generated by a surveillance facility and transmitted via a communications link, or derived directly from a convergence zone detection. Intelligence data includes the contact time and estimates of course speed and position.

Detection: VIM treats detection in one of three ways. The target responds to a detection of the attacker by executing an evasion pattern; the attacker may respond to a convergence zone detection by attempting to intercept the target; or at pot ·tial points of detection the probability with which the attacker detects the target is estimated with neither unit reacting to the event.

A counterdetection occurs whenever an evasion plan has been provided to the target and the signal excess at the target as determined from the sonar equation [2] is positive. Counterdetections are computed deterministically based on ship noise, sonar gain and range between units. At various times determined by the trial geometry, the probability that the attacker detects the target is estimated. This probability is computed using sonar equation for signal excess [2] under the assumption that the amount of reduction in noise level as sound propagates through the water is a normally distributed random variable. These estimates are combined to provide an overall estimate for each trial. See Chapter III, Section B for the details of this process.

Sonar detection opportunities arising for the attacker within a convergence zone (CZ) may result in one of two actions depending on the nature of the problem. If a CZ detection would satisfy the requirements of the attacker's mission, the detection probability estimate is combined with other probability estimates to form the overall estimate for each trial. If a CZ detection would fail to satisfy the attacker's mission, the detection probability estimate becomes the probability of a CZ intelligence detection at that point. If a CZ intelligence detection occurs the attacker attempts to intercept the target based on the CZ intelligence information.

B. DATA

The data required for operating VIM falls loosely within six categories: environment, identification, options, situation, target track and intelligence. While a certain amount of overlap exists among these categories, they are treated as distinct data units by the model.

Environmental Data: This data group contains the radiated and self noise curves of both units along with the propagation loss curve for the geographical area being considered.

Identification data: This data group contains information to assist the user in distinguishing the output from among various experimental runs and identifying the significant features of each run.

Option data: This data group contains information of an administrative nature which defines the way in which VIM will treat the various aspects of the simulation. Typical of the option data is the number of trials to be run, the level of output detail desired, and the method of generating intelligence.

Situation data: This is a general category which includes all data not required elsewhere. Typical situation entries are attacker operating speeds, initial target position, target evasion parameters and intelligence error parameters.

Target track data: This data defines the target's transit path. Included with each leg of the target track is an estimate of the vulnerability of the target to detection by the surveillance facility during the leg.

Intelligence data: If the observed output of a surveillance system is to be duplicated, it is entered as intelligence data. Acquisition time, position error, course and speed estimates may be listed. Information not supplied will be generated randomly by VIM.

III. DETAILED MODEL DESCRIPTION

This chapter contains a detailed exposition of the methods used in VIM to simulate the various facets of the submarine versus submarine search and detection problem. Section A is a discussion of each phase of the simulation including the options available for use in examining a wide variety of situations. Section B is an outline of overall program flow in terms of trial events. Section C deals with the function and logic of each subroutine as it relates to the overall program.

A. MODEL DETAILS

For the purposes of this discussion, VIM is divided into seven categories: target motion, convergence zone detections, intelligence, communications, attacker motion, detection and evasion.

Target motion: The target is provided an initial position and a sequence of future courses, speeds and times. The target procedes on the first course and speed until the problem time indicates a change is required. Except for the initial position the target track is independent of target location, being defined in terms of course, speed and time to start subsequent legs. The target will deviate from its assigned track in order to execute an evasion maneuver, but will resume the base course and speed when evasion has been terminated. If desired, target initial position and the course and speed on each leg can be varied randomly. In this case, the course and speed taken by the target after evasion will be randomly determined at that time.

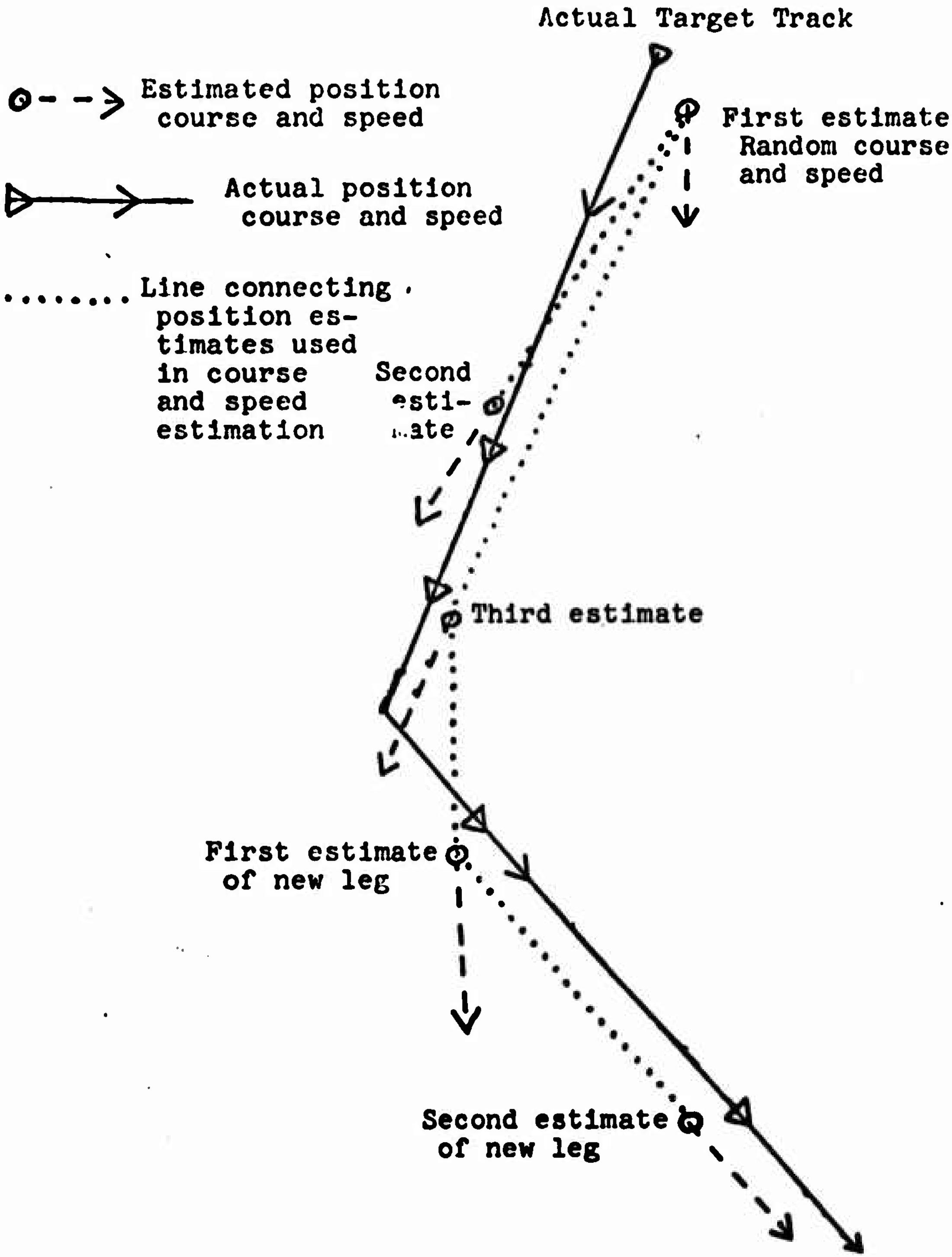
Convergence zone detections: One of two alternative interpretations may be selected for CZ detection opportunities. If a CZ detection of the target by the attacker may be adequate to fulfill the attacker's mission, then for each period the attacker spends within the convergence zone, a single detection probability is estimated when the range between the ships is as near the central CZ radius as it is expected to get. This probability estimate is treated in the same way as all other such estimates. If a CZ detection would fail to satisfy the attacker's mission the detection probability estimate generated within the convergence zone is understood to be the probability of a CZ intelligence detection to which the attacker will respond as if it had received intelligence from the surveillance facility. CZ intelligence data is generated randomly based on convergence zone parameters and cannot be combined with surveillance intelligence. CZ detection probability estimates are not combined with other detection probabilities if the CZ intelligence option is exercised.

Intelligence: Intelligence data generated by a surveillance facility may be developed in one of several ways: all data input; some data input, the remiander created within the program; or, all data created within the program.

Within each of the latter two categories several options are available. If all data is to be input, the acquisition time of the intelligence, the position error relative to the actual target coordinates and the course and speed estimates for each surveillance facility detection are required. The course and speed estimates may be omitted from the input data and will be selected randomly or computed from position estimates. Figure 1 shows an example of typical course and speed estimates based on intelligence positions. Omission of the position error from the input data will result in a random error generated at the time of the intelligence acquisition. If all intelligence is to be generated within the program, no intelligence data is entered. The times of acquisition are random based on the susceptibility of the target to the surveillance system on each leg. Position, course and speed errors are determined as indicated above.

Communications: At periodic intervals throughout each trial the attacker monitors an intelligence broadcast which provides the information generated by the most recent surveillance detection subject to a fixed delay time. The interval between broadcasts is an input parameter for the attacker transit phase, but is set to two hours during the search phase. A continuous broadcast monitoring option is available whereby intelligence is provided to the attacker immediately following the fixed delay.

Figure 1. Intelligence Course and Speed Estimates Based on Position Estimates



Attacker motion: Attacker motion is governed by one of three situations: initial waiting station, response to intelligence and search for the target. At the beginning of each trial the target is on waiting station proceeding on an input course and speed. It will continue on the initial vector until receipt of an intelligence estimate regarding the target. In response to the intelligence, transit speed is taken and course is determined to intercept the target based on intelligence information. The search phase begins when the attacker reaches the expected intercept point. The attacker assumes its assigned search speed and searches back and forth perpendicular to the estimated target tracks on legs of specified duration. The search phase continues until new intelligence information is received.

Detection: The sonar equation for figure of merit [2] is

$$FM = Nr - \max\{Ns, Na\} + Nrd - Ndi$$

where Nr is the noise level in decibels (db) radiated by the source;

Ns is the background noise in db at the receiver;

Na is the ambient noise level of the ocean in db;

Nrd is recognition differential: the ability of the system to distinguish between signal and random noise;

Ndi is directivity index: the ability of the system to identify the direction from which a signal is coming;

Nrd-Ndi: measured in db is treated herein as the single entity, sonar gain.

Propagation loss, L, is a measure of the reduction in noise level in db as sound is propagated through the water. L is a function of the range from the noise source and is assumed in VIM to have a normally distributed error. Signal excess, Se, is defined as Se = FM-L, and is also a normally distributed random variable with the same variance as L. When Se is zero the probability of detection is assumed to be 1/2.

Detection probability, p, is estimated from the formula

$$p = \Phi(Se/s)$$

where $\Phi(z)$ is the probability that a standard normal random variable will be less than z, and s is the standard deviation of propagation loss. For example, if FM = 109 db, L = 95.5 db and s = 9 db, then Se = 13.5 db, Se/s = 1.5 and p = .93. In developing the aggregate probability estimate, $\bar{P}$, for the trial it is assumed that each estimate is independent and

$$\bar{P} = \bar{P}' + p(1-\bar{P}')$$

where $\bar{P}'$ was the overall probability prior to the estimate p.

Probability estimates are generated at the start of each event and after any course or speed change by either ship, but are only included in the overall estimate under the following circumstances:

1. the attacker is in transit to a search station and a course or speed change by either unit results in a change from decreasing range to increasing range;

2. the attacker is in transit to a search station and achieves closest point of approach;

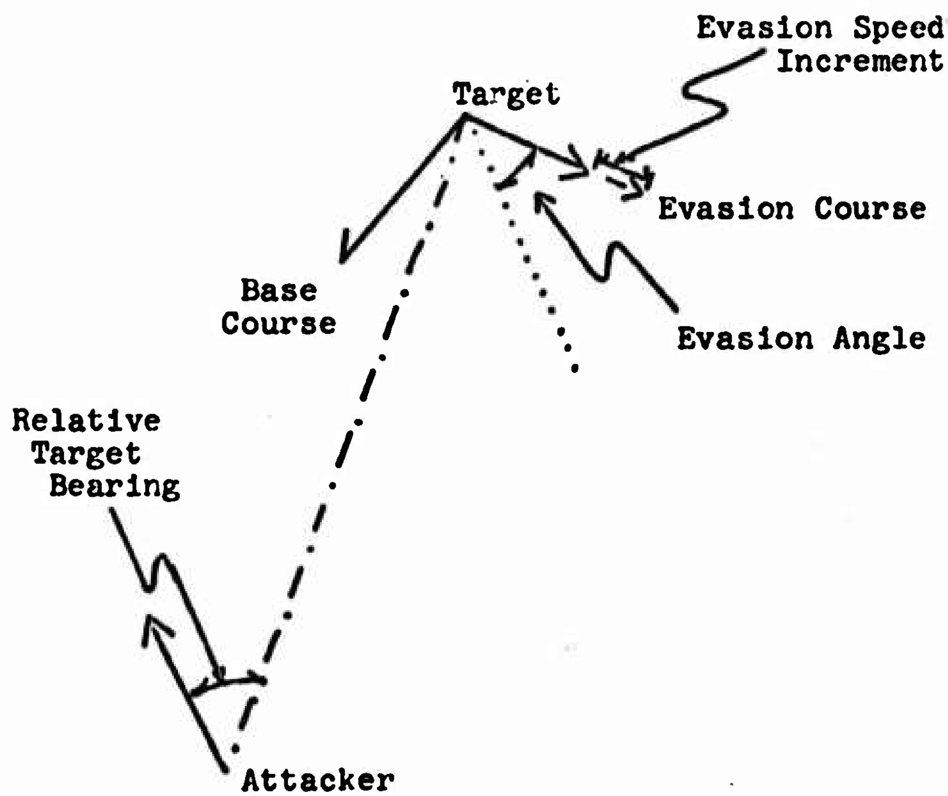
3. the attacker is on search station and achieves its maximum detection probability during that search phase; or

4. the attacker is within a convergence zone and is as close as expected to the central radius and the CZ intelligence option was not selected.

Under the CZ intelligence option detection probability generated within a convergence zone is taken to be the probability of a CZ intelligence detection, and CZ probability estimates are not included with the trial estimate.

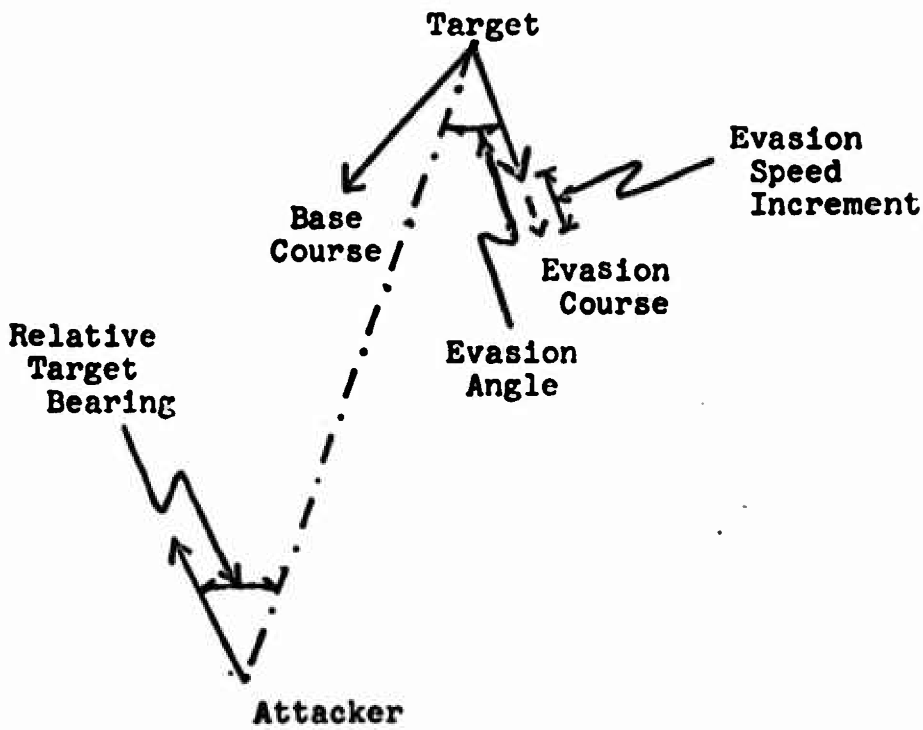
Evasion: Four prepared evasion patterns are available to the target with provisions for a fifth pattern if desired. In pattern 1 the target reverses course and reduces speed by one half. Pattern 2 calls for a clockwise course change and a speed change. In pattern 3, illustrated in Figure 2, the target changes course relative to the bearing of the attacker away from attacker track and changes speed. In pattern 4, illustrated in Figure 3, the course change is relative to the attacker course away from its track and speed is changed. Except in pattern 1 the magnitudes of the course and speed changes along with the evasion interval

Figure 2. Evasion Pattern 3



If relative target bearing is less than 180° the evasion angle is subtracted from the reciprocal of target course. If relative target bearing is greater than 180° the evasion angle is added.

Figure 3. Evasion Pattern 4



If relative target bearing is less than 180° the evasion angle is subtracted from the true bearing of the attacker. If relative target bearing is greater than 180° the evasion angle is added.

are inputs. Evasion is terminated after the fixed interval or when a new target track leg is ordered.

Provision is made for the user to introduce his own evasion routine. The calling sequence is controlled by the normal input parameters.

If the target has been assigned an evasion routine, counterdetections will occur when a deterministic evaluation of the sonar equation indicates Se is positive. Counter-detections are supressed during the evasion maneuver.

B. TRIAL EVENTS

VIM is composed of a sequence of events, each event occuring at a time determined by previous events, randomly or input. At each event, the positions of the target and attacker are updated, the appropriate action dictated by the event is executed, if necessary new event times are generated, data is stored or printed and the trial clock is advanced to the time of the next event.

Target Course Change: The target assumes the course and speed of its next leg. Upon executing a course change the target terminates evasion and sets its course and speed to the next assigned values either exactly or randomly. Using the new course and speed the expected time of closest point of approach (CPA), counterdetection time, detection probability and CZ detection time are calculated.

Counterdetection: A Counterdetection event signals either the commencement or termination of evasion. If no evasion is specified counterdetections are supressed. At the time of counterdetection the target commences its evasion routine and the next counterdetection event is set to occur after the evasion interval. Time of CPA, detection probability, CZ detection time and, at termination of evasion, counterdetection time are computed.

Intelligence Detection: This event generates the results of a detection of the target by a surveillance facility in accordance with the desired option. The data is stored for later release to the attacker. Neither ship responds to an intelligence detection.

Convergence Zone: This event results in a detection opportunity for the attacker. If the CZ intelligence option has been selected, the detection probability estimate is taken to be the probability of a CZ intelligence detection. If a CZ intelligence detection occurs the intelligence data is computed based on parameters compatible with the submarine versus submarine tracking problem, and the attacker responds to it as it would to surveillance intelligence received during a communications period. If a CZ intelligence detection fails to occur no action results and the event is terminated. When CZ intelligence is not desired, but a convergence zone is present, the CZ probability estimate is combined with other estimates to form the overall trial probability estimate. No response by either unit is required. The CZ event occurs once for each passage through the convergence zone.

Communications: This event provides the opportunity for new intelligence data from the surveillance facility to be provided to the attacker. At the time of a Communications event the list of intelligence collection times is searched for the latest time which precedes current time by more than the fixed delay. If the data has been previously transmitted to the attacker or has been superceded by CZ intelligence the event is terminated. If the intelligence data has not been previously transmitted a course is determined by which the attacker will intercept the estimated target. The new CPA time, counterdetection time, convergence zone time and detection probability are computed. If the attacker is on search station the maximum detection probability of that search phase is combined with other probability estimates to form the cumulative trial estimate of detection probability.

Detection Probability: The current detection probability estimate is either combined with other estimates to form the overall trial probability or used in the selection of a maximum search probability depending on the tactical situation. If the attacker is in transit to an intercept point, the current probability estimate is combined with the previous probability estimates to produce the cumulative trial estimate. If the attacker is on search station the estimate is compared with all previous estimates generated during the search pattern and if it is the maximum it is retained for later reference. Otherwise it is dropped and the event is terminated.

Attacker Course Change: This event indicates an attacker course and speed change upon arrival at search station and at the end of each search leg. Course changes related to new intelligence are either communications events or convergence zone events and are not referred to as attacker course change events. The attacker's search station is centered at a point determined by the intersection of the attacker's transit track and the estimated target track. Upon arrival at the center of the search station the attacker assumes a course 90 degrees clockwise from the estimated target course and procedes at search speed for one half the time allotted for a search leg. At the end of the search leg the attacker reverses course and searches in the new direction for the entire prescribed interval. Each attacker course change event is accompanied by computation of new CPA time, counterdetection time, detection probability and convergence zone time.

End of Trial: The trial is terminated when no further positive detection probabilities are expected and in any case when trial time exceeds a nominal termination time by 100 hours. The specific criteria for ending a trial are:

1. The final intelligence estimate of the trial has been transmitted to the attacker,
2. The attacker is on search station,
3. Probability of detection is zero, and
4. The range of the target to the search station is increasing.

In addition to the above criteria, if the final intelligence of the trial results in an estimated speed advantage for the target so that intercept appears impossible the trial is terminated.

If the attacker is on search station at the end of the trial maximum detection probability generated during the final search phase is included in the overall probability estimate for the trial. All trial statistics are recorded for summary display and the next trial is begun.

C. LOGIC AND SUBROUTINES

This section contains a description of the main program, MAIN, logic flow, illustrated in Figure 5, along with an explanation of each of the subroutines. Program activities can be categorized as run preparation, trial preparation, event execution and display, trial completion and run completion. Figure 4 shows the relationship of each of the categories. The details of each activity are best found by examining Figure 5 and the explanations of subroutines referenced within the figure.

MAIN controls the sequence of operations during the execution of a series of runs. Run preparations involve the reading and display of input data and are carried out at the beginning of each run. The environmental inputs are read in before the first run only. Trial preparations precede each trial and include initializing key variables and developing the event list. For each trial, MAIN

Figure 4. VIM Logic Summary

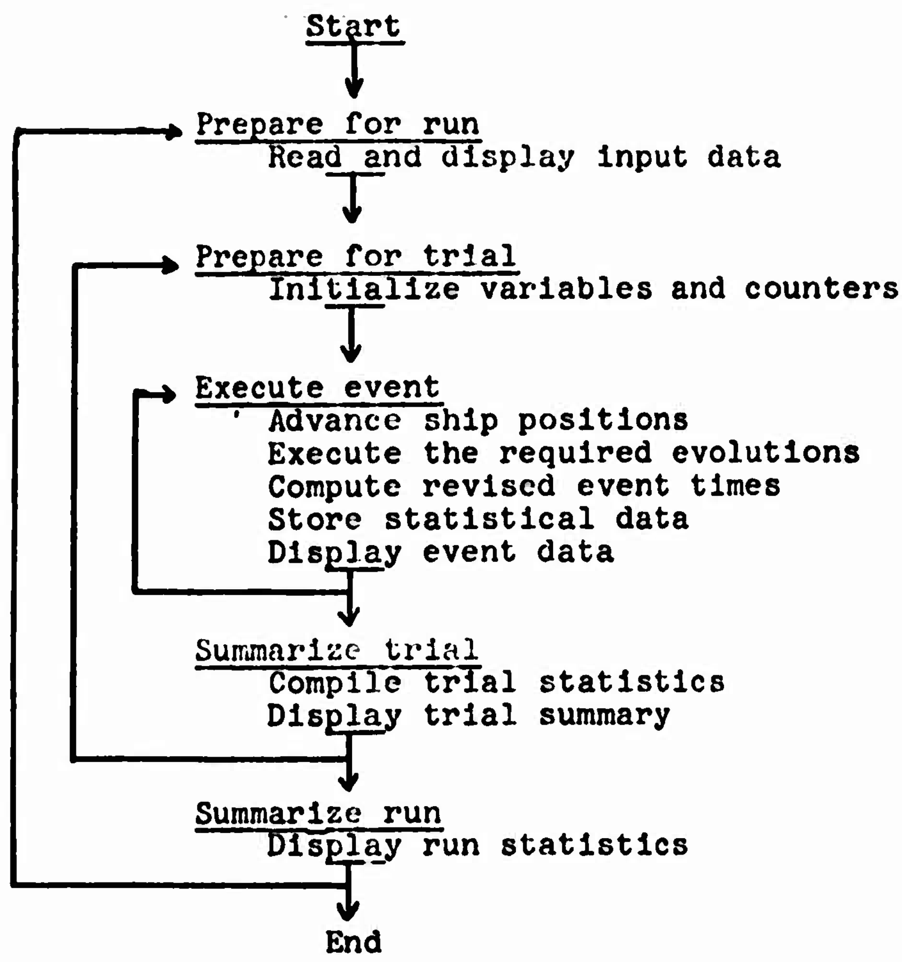


Figure 5. Main Program Flow Chart

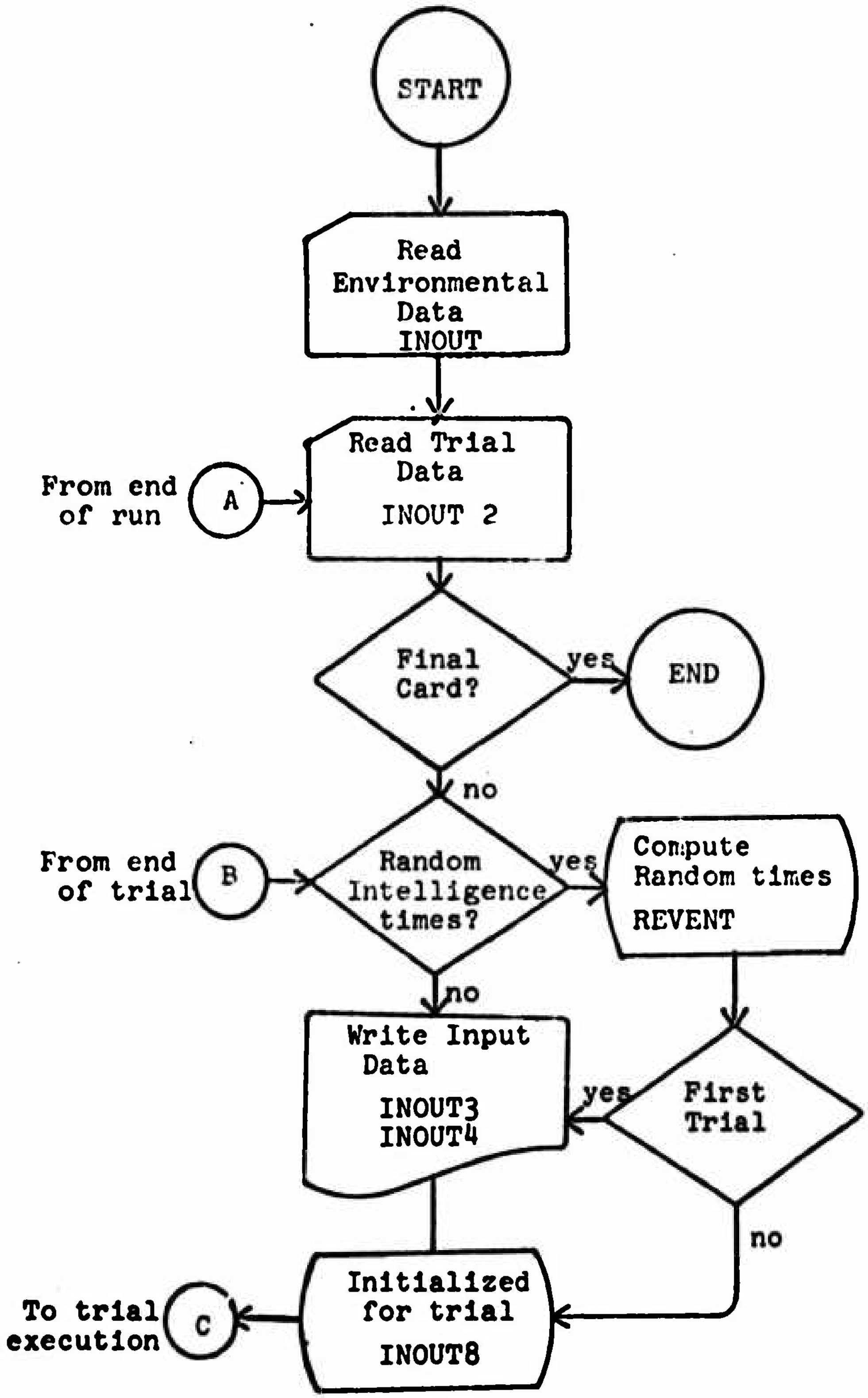


Figure 5. (Continued)

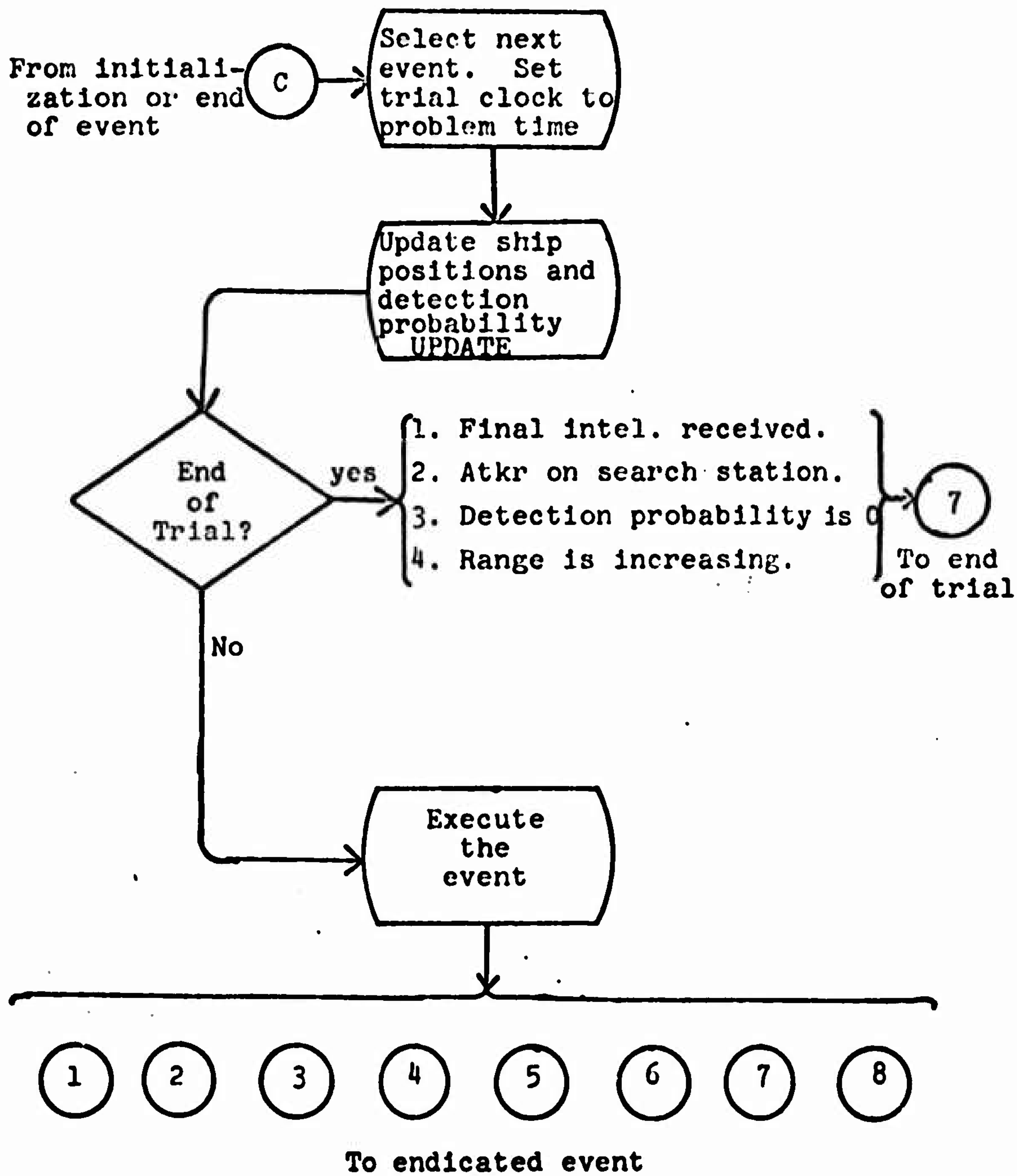
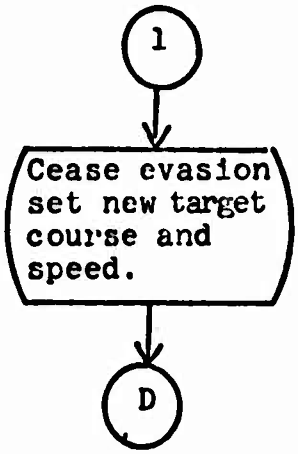


Figure 5. (Continued)

Event type 1: Target course change



To new event times

Event type 2: Surveillance system detection

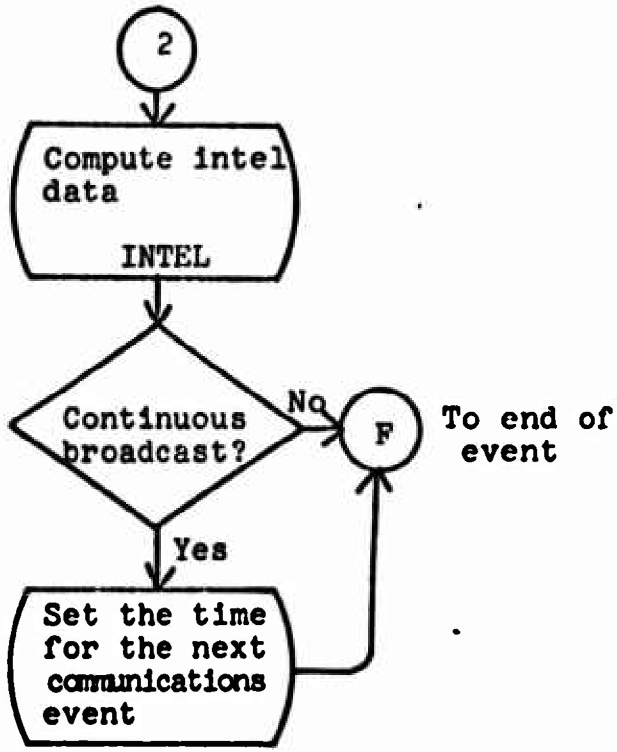
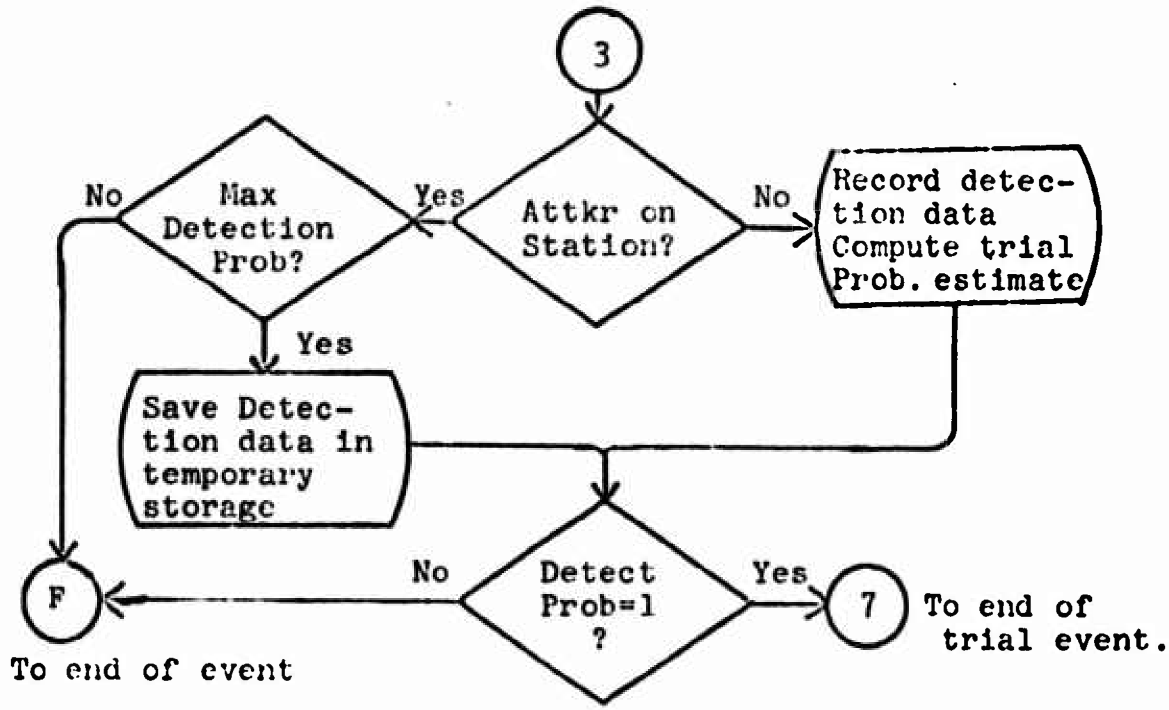


Figure 5. (Continued)

Event type 3: Detection probability



Event Type 4: Counterdetection

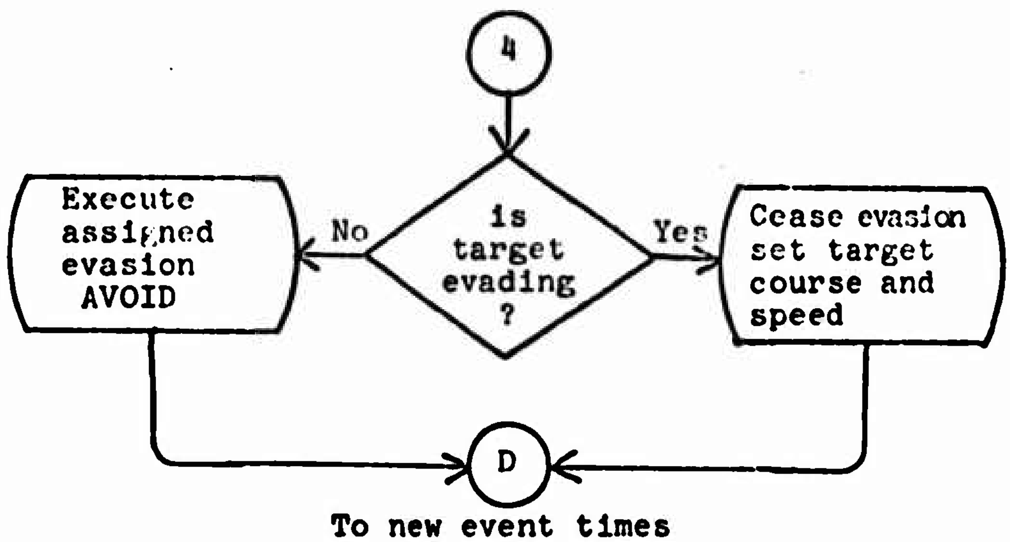
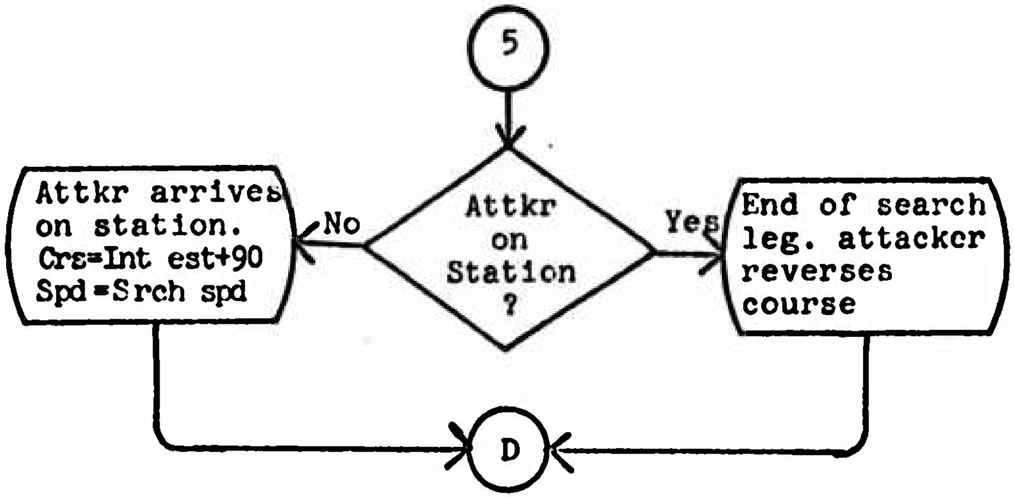


Figure 5. (Continued)

Event type 5: Attacker course change



Event type 6: Communications period

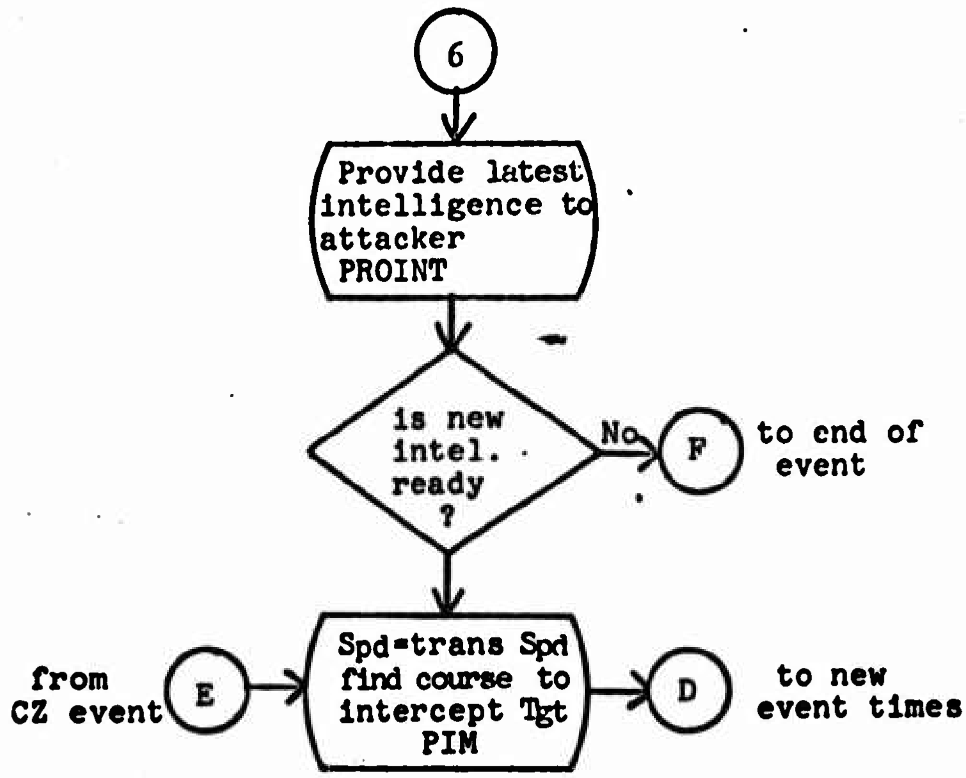
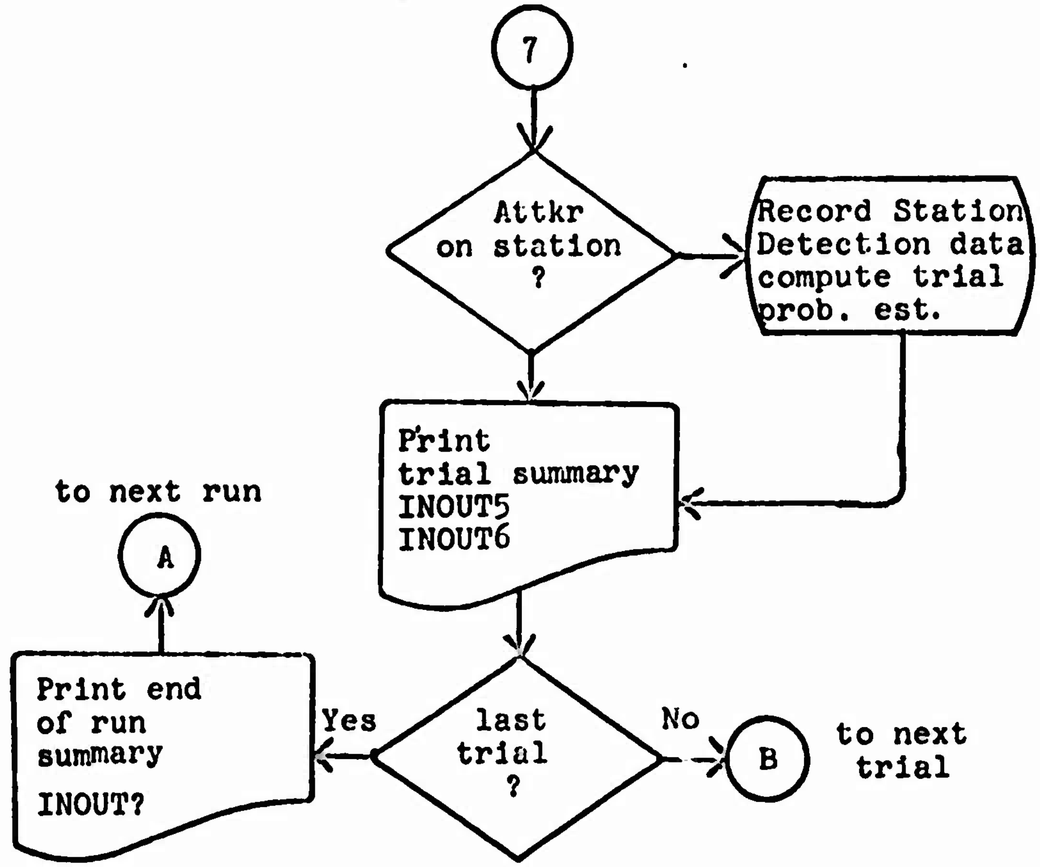


Figure 5. (Continued)

Event type 7: End of trial



Event type 8: Convergence Aone

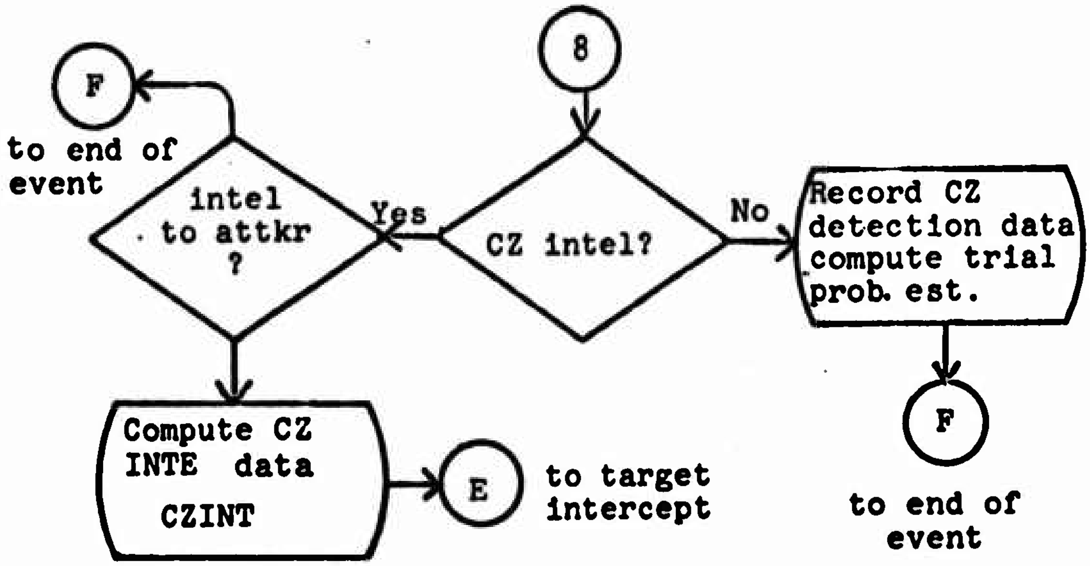


Figure 5. (Continued)

Revise Event Times

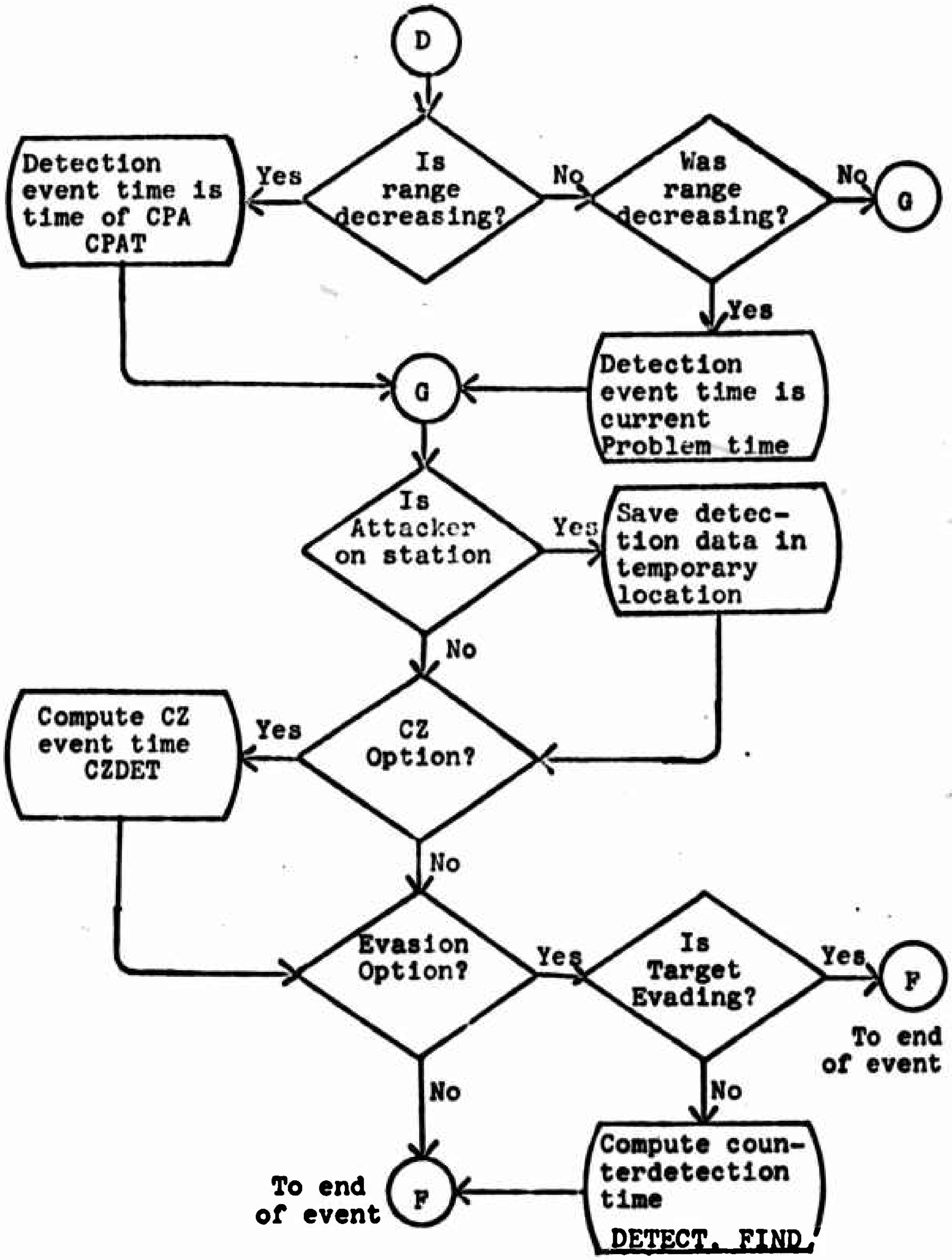
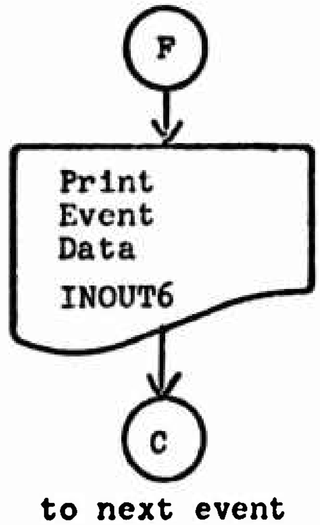


Figure 5. (Continued)

End of Event



executes the events in chronological order until the trial termination criteria are satisfied. Following each trial, MAIN directs the data assembly for the trial and the desired output, then initiates the next trial or run summary as appropriate. Following the run summary, the pattern is repeated starting with run preparations until all runs have been completed.

While primary control of VIM rests within MAIN many of the details of the simulation are contained in subroutines which are called by MAIN and other subroutines. In the text that follows, these subroutines will be referred to by name and are listed in order of their appearance in the program listing, Appendix B.

INOUT: The input and output functions are performed primarily by INOUT. These functions are described in detail in Chapter IV. In addition to reading all input data and writing most of the output messages INOUT initializes trial variables and prepares the statistical data for display. Eight entry points are provided and are called only by MAIN at various critical times throughout the series of runs.

Entry INOUT: This routine reads tille card and environmental data is the preliminary step in a series of runs.

Entry INOUT2 : This routine reads run designator, run description, options, situation, target track and intelligence data in preparation for each run. Optimal target intercept is computed.

Entry INOUT3: This section of INOUT displays the input data at the start of each run.

Entry INOUT4: New random intelligence times are printed by this routine at the start of each trial if desired. Counters used in compiling run statistics are set to zero.

Entry INOUT5: At the end of each trial this routine accumulates statistics for inclusion in the run summary. If desired the trial summary is displayed.

Entry INOUT6: At the end of each event statistics pertaining to the event are stored and if desired the trial status is printed.

Entry INOUT7: At the end of each run this routine calls subroutine STAT to compute the means and variances of each of the data groups compiled during the run, and prints the run summary.

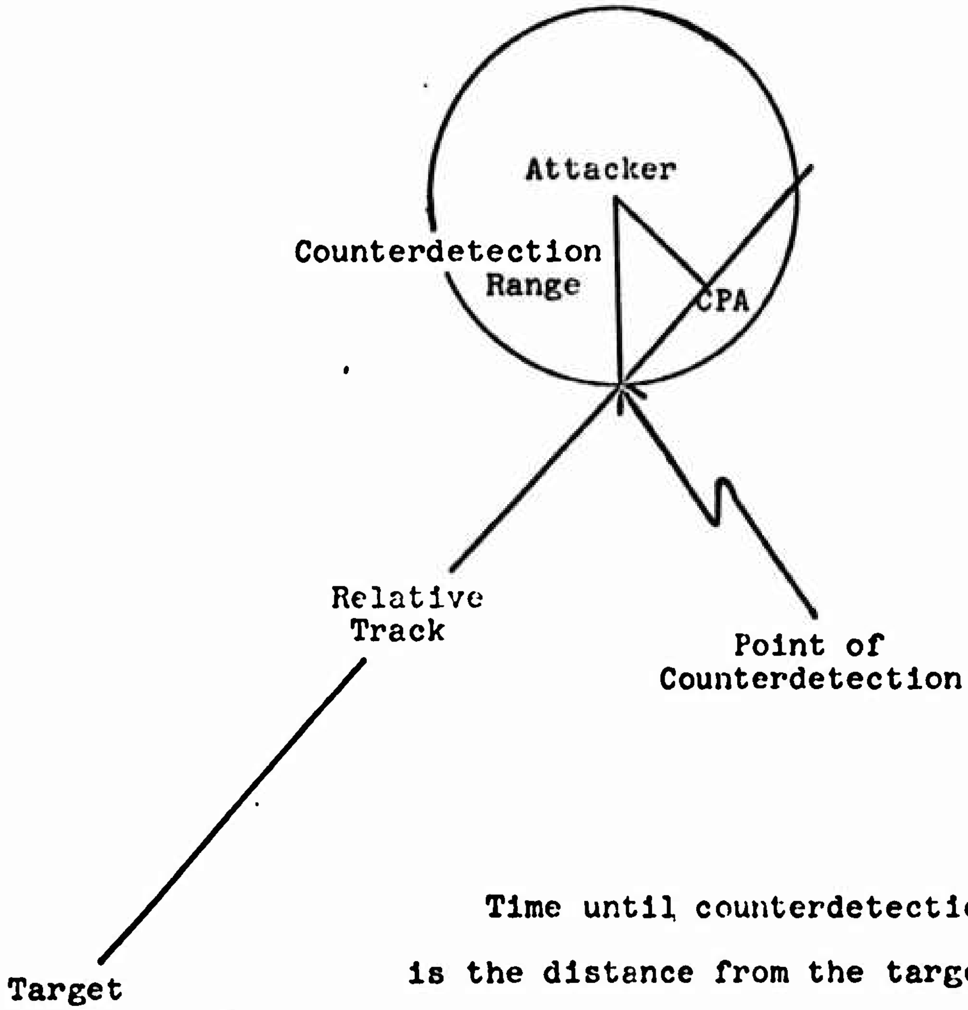
Entry INOUT8: Before each trial this routine sets all key variables to their initial values, generates the times of the first expected detection events using subroutines CPAT, DETECT, FIND, and CZDET. The subroutine ELIST is called to establish the event calendar for the trial.

UPDATE: This subprogram computes the attacker and target coordinates at the time of the current event using the coordinates of the ships at the time of the previous event and the X and Y velocity components. With the new positions the range, rate at which range is changing and the status of the attacker with respect to the convergence zone are calculated. Subroutines DETECT and PDET are called to provide the current detection probability estimate.

FIND: This routine computes the expected counterdetection time based on the relative speed vector and counterdetection range, R, during trial initialization and after each event which results in a course or speed change for either unit. (Fig. 6) If present range is greater than R and range is increasing counterdetection will not occur. When the range is closing from a distance greater than R, then CPA range and CPA coordinates are computed. If CPA range, Rc, is greater than R a detection will not occur. If Rc is less than R the time of counterdetection is determined to be the time at which range between the units will equal R. If present range is less than R counterdetection is immediate.

CPAT: This routine computes the time required for the attacker to achieve its closest point of approach based on the relative speed vector during trial initialization and after each event which results in a course or speed change for either unit. The time thus computed will be used as the time of the next detection probability event. If the range is increasing following a course change, but had been decreasing, the CPA time is current problem time. If the range is decreasing following a course change the coordinates of the closest point of approach relative to the attacker

Figure 6. Determination of Time Until Counterdetection Using Subroutine FIND



Time until counterdetection is the distance from the target to the point of counterdetection divided by relative speed.

are determined and the time required for the attacker to reach that point is computed based on the relative velocity vector.

DETECT: This routine evaluates the sonar equation as the preliminary step to computing counterdetection time and probability. The parameters for the sonar equation are compiled using the self and radiated noise curves and the ship speeds. The ship noise data is combined with ambient noise and sonar gain to form the figure of merit. If a detection probability is being computed, the figure of merit is returned to the calling program for use with subroutine PDET. If counterdetection time is to be established, the range of zero signal excess is determined from the propagation loss curve and is returned to the calling program for use in subroutine FIND.

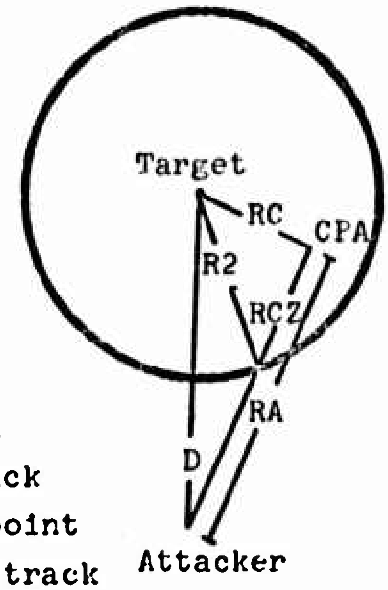
CZDET: This routine computes the time until the next CZ event during each course or speed change by either unit. Figure 7 is a logic flow diagram of CZDET. The convergence zone is defined in terms of its inner, central and outer radii. CZ event times are determined as follows:

1. Range between the ships is greater than the outer CZ radius, and
    a. CPA range is less than the central CZ radius: the event occurs when the range equals the central CZ radius,
    b. CPA falls between central and outer CZ radii: the event occurs when the ships reach CPA, or

Figure 7. Subroutine CZDET

Variable Definitions:

- R1: Inner CZ radius
- R2: Central CZ radius
- R3: Outer CZ radius
- D : Range between ships
- VR: Relative Speed
- RA: Distance from attacker to CPA along relative tracks
- RCZ: Distance from CPA to central CZ radius along relative track
- DIST: Distance from attacker to point of CZ event along relative track
- IRUN: A status switch
- TF: Time until next CZ event



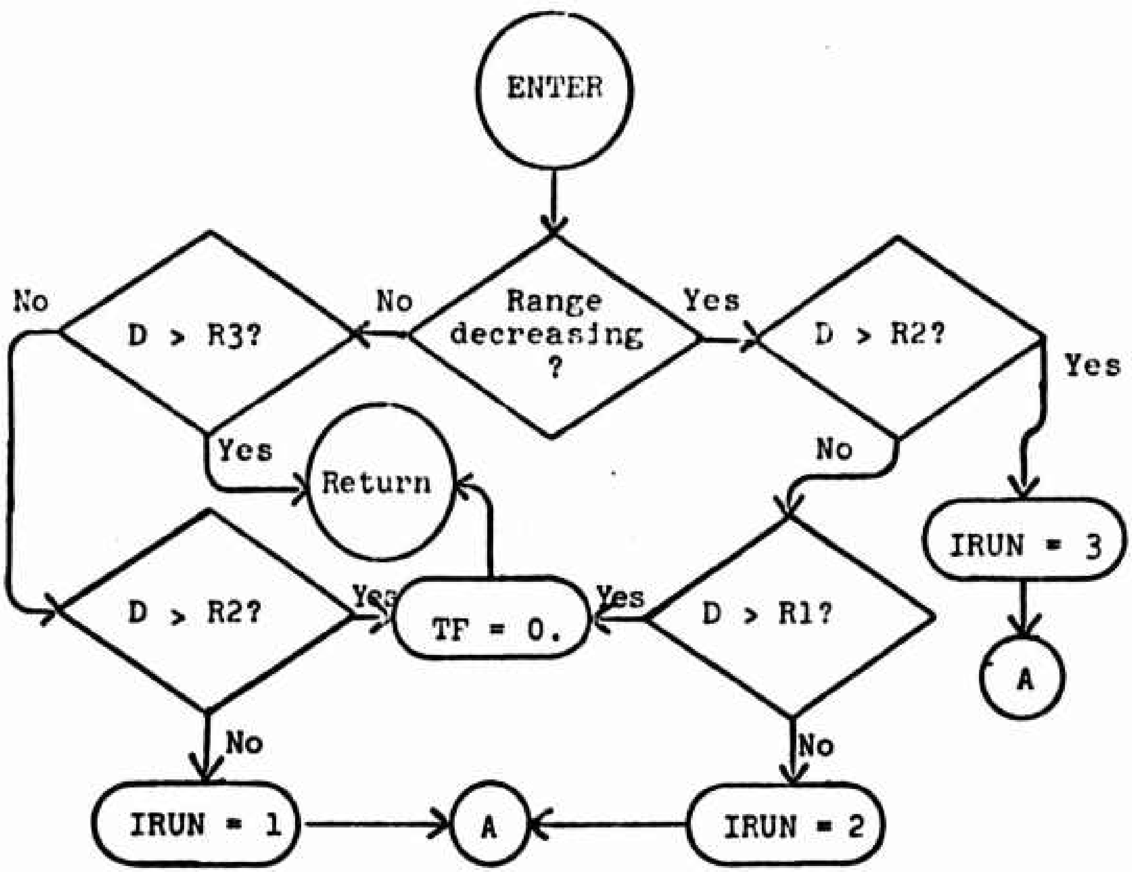
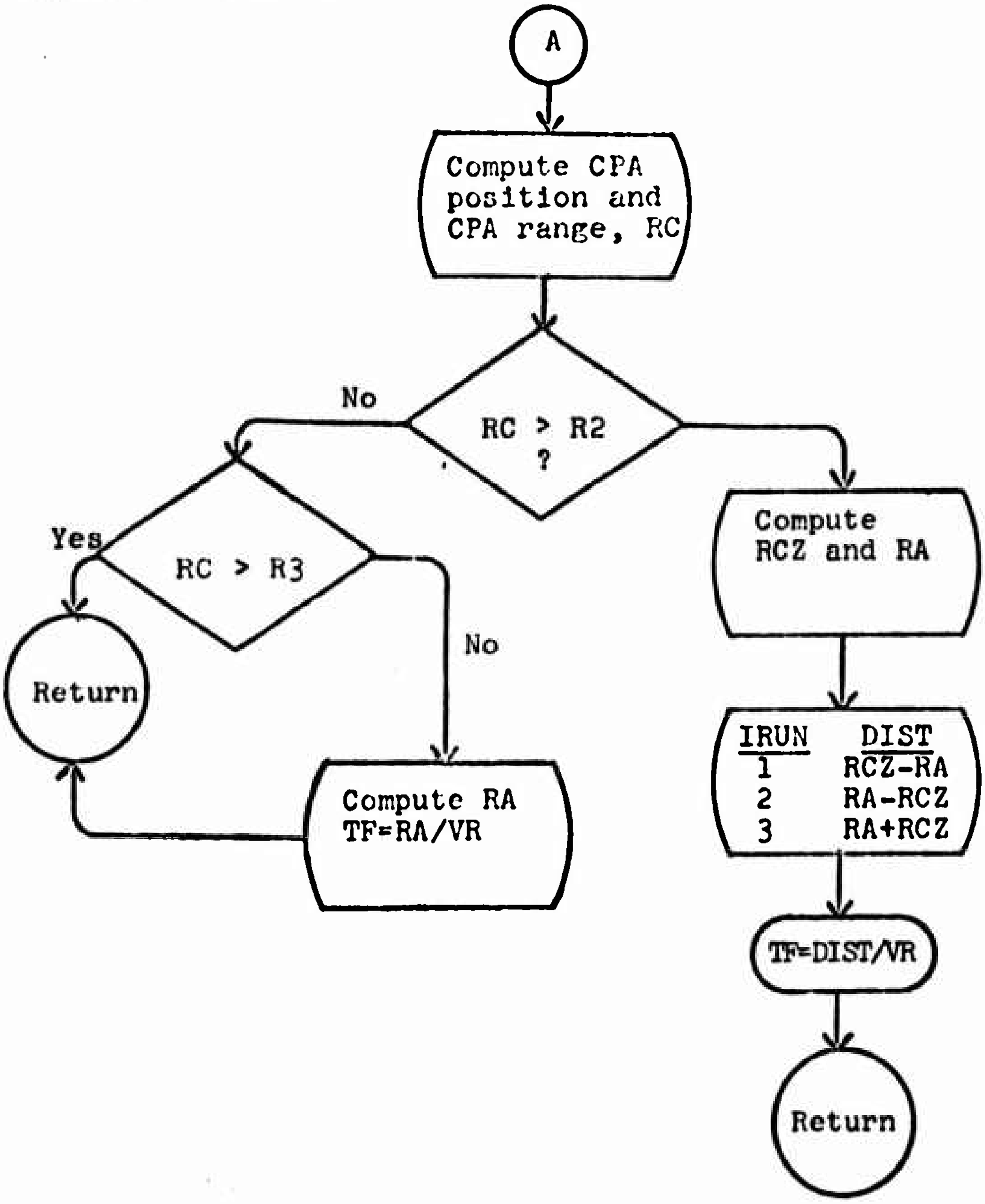


Figure 7. (cont.)



c. CPA range is greater than the outer CZ radius: no event will be scheduled.

2. Attacker is within the convergence zone, and

a. A CZ event has already occured during this period within the convergence zone: no event will be scheduled,

b. Range is increasing and greater than the central CZ radius: the event time is current problem time,

c. Range is greater than the central CZ radius and CPA range is less than central CZ radius: the event will occur when the range equals the central CZ radius,

d. Range is decreasing but CPA range is greater than central CZ radius: the event will occur when the ships are at CPA,

e. Range is increasing and less than the central CZ radius: the event will occur when the range equals the central CZ radius,

f. Range is decreasing and less than the central CZ radius: the event time is current problem time.

3. Range is less than the inner CZ radius: the event will occur when the attacker reaches the center of the convergence zone.

PDET: This routine computes the probability of detection at the beginning of each event, when the attacker arrives on search station and when the target changes speed at a new leg time or during evasion, based on the figure of merit and range between the ships. The propagation loss, L, at the given range is compared with the figure of merit, FM, to determine signal excess. Under the assumption that propagation loss is a normally distributed random variable with known standard deviation, s, then z = (L-FM)/s represents the number of standard deviations by which the propagation loss exceeds the figure of merit. The probability of detection is given by the probability that a standard normal random variable is greater than z. The value z is compared with the values given in a standard normal cumulative distribution table to obtain the probability estimate.

AVOID: This routine computes the course and speed used in response to a counterdetection. Figure 8 is a flow diagram of subroutine AVOID. Figures 2 and 3 illustrate two of the evasion patterns. The calling sequence for a special evasion routine is included and may be executed through normal inputs. The special evasion must be provided by the user as subroutine SPCL.

INTEL: This routine determines the course, speed and position resulting from a surveillance facility intelligence detection. Figure 9 shows the logic used in computing the intelligence estimate according to the desired option. All random error estimates are symetric about the actual value with the distribution parameter representing either the maximum error in the case of the uniform distribution, or two standard deviations of the normal distribution.

Figure 8. Subroutine AVOID

Variable Definitions

CT:	Target Course	ST:	Target Speed
B :	Bearing of attacker from target	BR:	Bearing of target from attacker
CA:	Attacker Course	EVANG:	Input evasion angle
EVSPD:	Input speed increment	N :	Evasion pattern

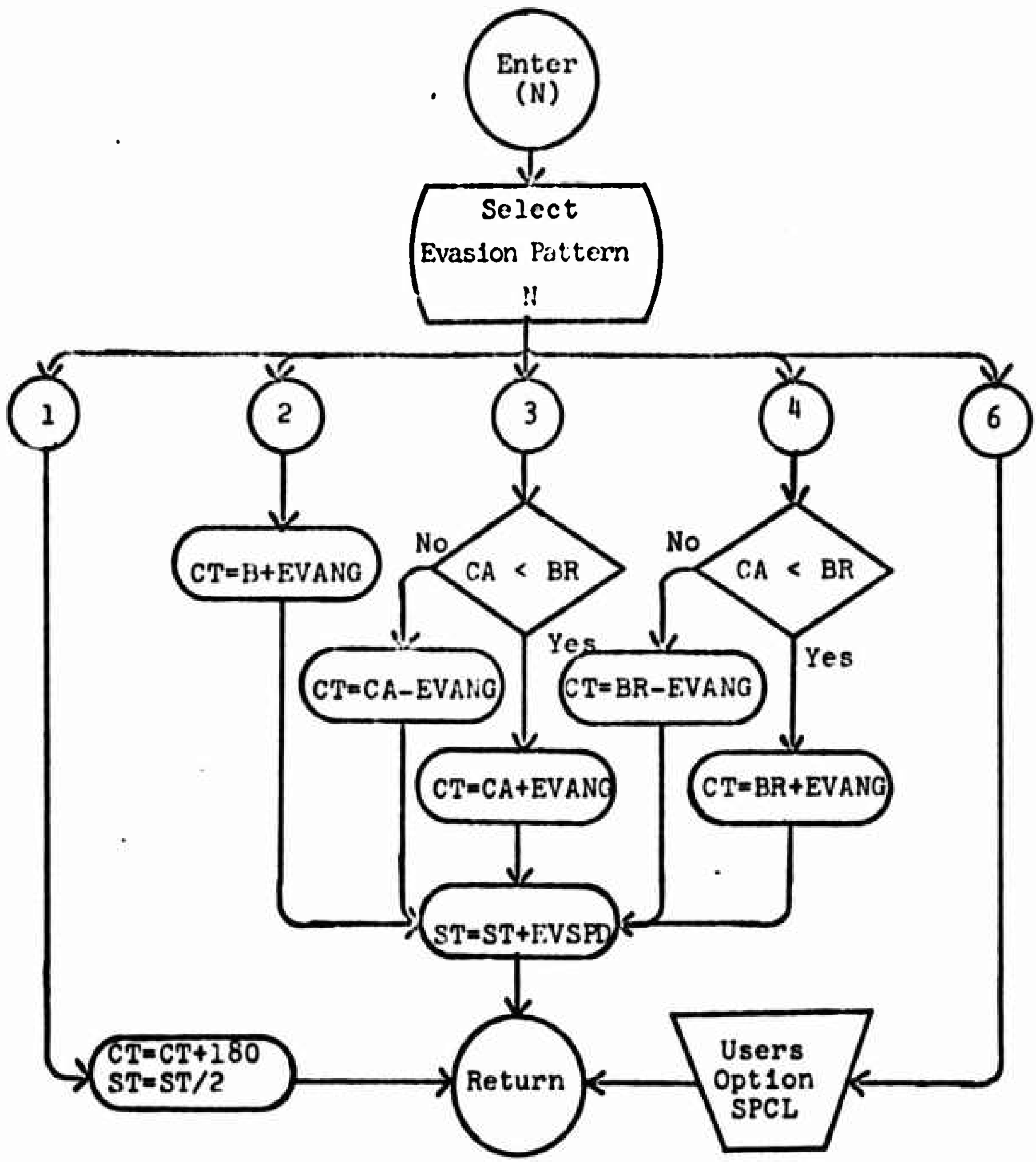
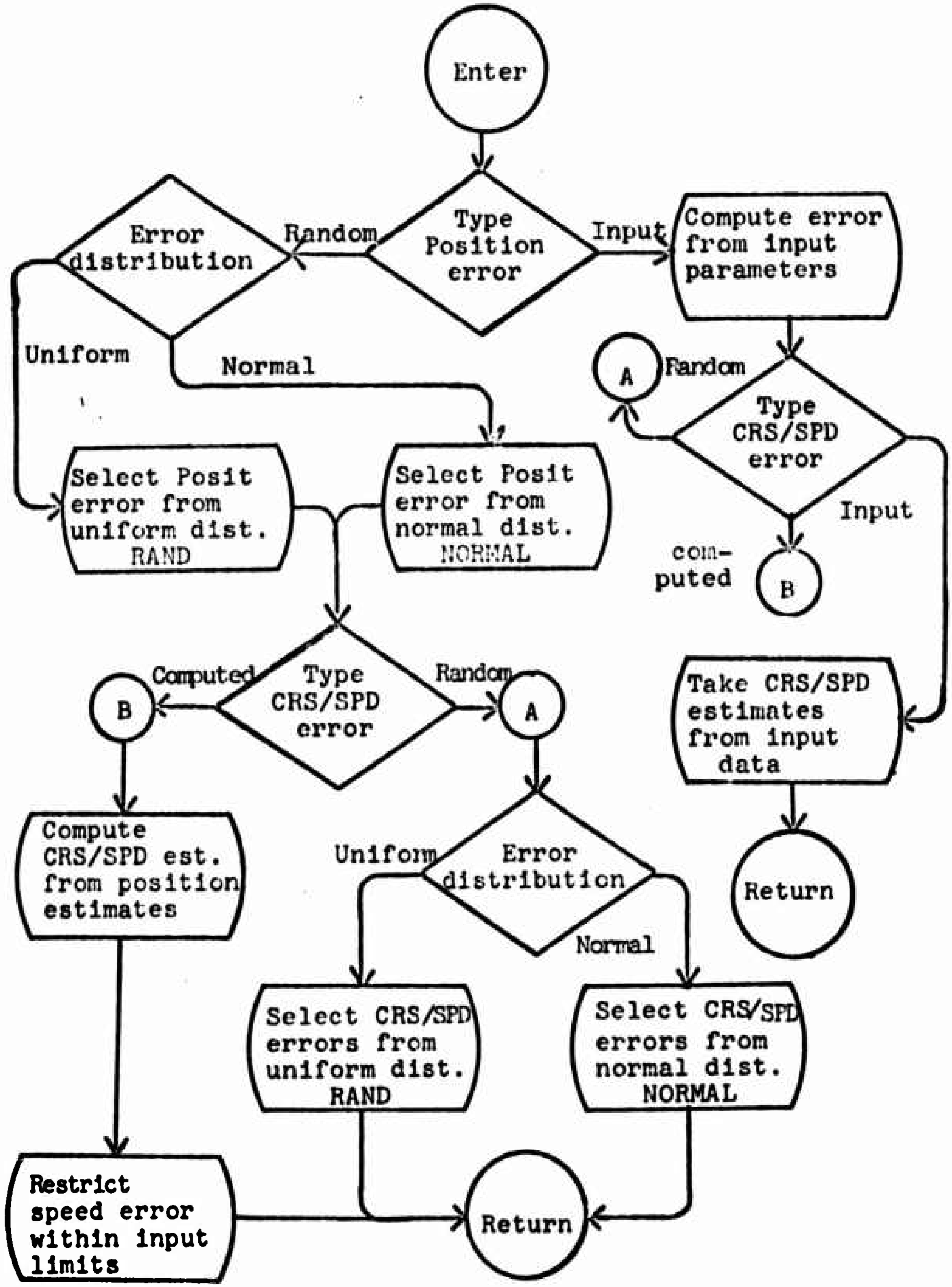


Figure 9. Subroutine INTEL



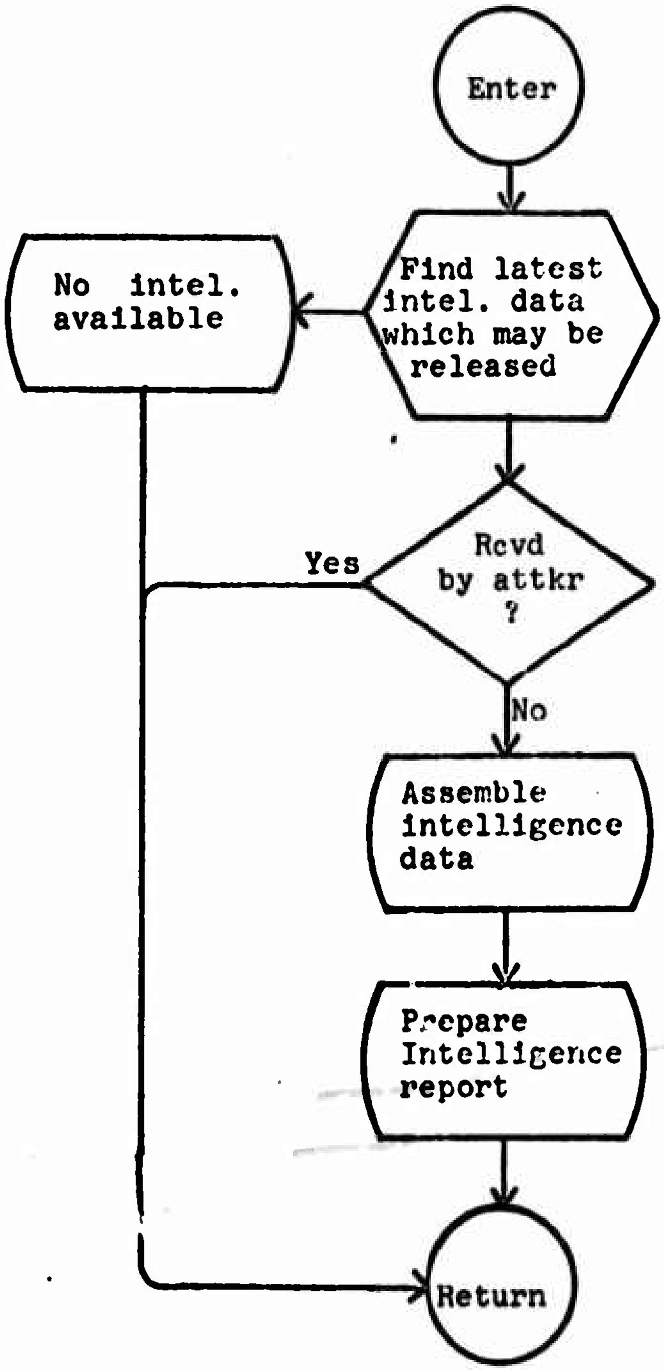
Computation of course and speed estimates based on position error is shown in Figure 1. The first estimate is random from a uniform distribution. The first estimate on a new leg uses current and previous intelligence positions. Other estimates are based on current position estimate and the first position estimate for the leg. CZ intelligence is not used.

INTDET: This routine calls INTEL to prepare an intelligence estimate, then stores the information received. If target course and speed are to be computed based on position errors, the base data is generated for the first intelligence detection and updated after each target course change. If desired intelligence data is printed.

PROINT: This routine provides the attacker with the latest data which is available at a communications period but has not been previously transmitted or superceded by a CZ intelligence detection. If any such data exists, the position estimate is advanced to the current time according to the estimated course and speed. Attacker speed is set to transit speed. Figure 10 is a flow diagram of subroutine PROINT.

CZINT: This routine generates the convergence zone intelligence data when required. The course, speed, range and bearing errors are selected randomly from uniform distributions using subroutine RAND. Range and bearing errors are converted into X and Y coordinates representing the estimated target position.

Figure 10. Subroutine PROINT



ELIST: This routine initializes the event calendar. The event calendar consists of a list of event times and a list of corresponding event types. The event calendar contains all target track times, all intelligence detection times, the times of the next communications event, the next detection probability event, the next counterdetection event, the next attacker course change event, the next CZ event and the mandatory end of trial event. With times assigned to all events the lists are arranged in chronological order.

RPLACE: This routine inserts revised event times in the event calendar. At various times throughout the execution of a trial Detection, Counterdetection, Attacker Course Change, Convergence Zone and Communications event times must be revised. When a revised time is generated, the event calendar is searched for the previously scheduled time of the event and it is replaced with the revised time. The revised time is then sequenced within the event calendar.

STAT: End of run sample means, M, and sample variances, V, are computed for all statistical data compiled during the run. Zero valued data may be ignored as in the case of the times of maximum detection probability for trials in which no positive probability of detection was generated.

Sample mean is

$$M = \frac{\sum_{k=1}^{n} X_k}{n}$$

where n is the number of data points, X_k , being averaged.

Sample variance is

$$V = \frac{\sum_{k=1}^{n} (X_k - M)^2}{n - 1}$$

CURVE: This is a table look up routine. A table consists of two lists of corresponding entries. Given a value in the range of one of the lists, the corresponding value is selected from the other list. When the calling argument does not correspond to a table entry, a linear interpolation between the adjacent entries is performed to produce the corresponding value. If the calling argument is outside the range of the list, the segment defined by the two data points nearest the input argument is assumed to extend indefinitely and the output value is determined accordingly. Figure 11 illustrates a typical propagation loss curve. R_1, R_2 and R_3 represent calling arguments with L_1, L_2 and L_3 the returned values. In Figure 12 F_1 and F_2 are the calling arguments returning R_1 and R_2, the expected counter-detection ranges corresponding to the given figures of merit. Radiated and self noise curves always use speed as the calling argument.

ORDER: This routine arranges the event times in chronological order. On initializing for each trial and each time an event is rescheduled. There are three entry points for order.

Entry ORDER: This section is used to order the entire list during initialization. For this operation the

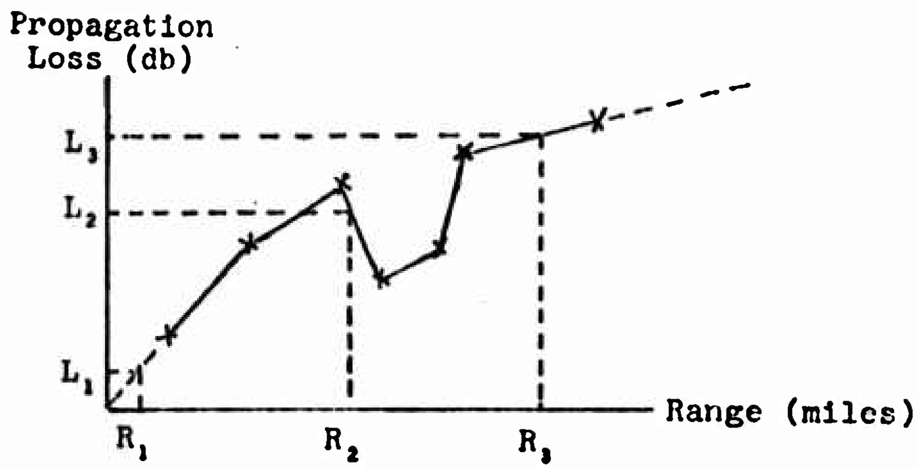


Figure 11. Examples of estimating propagation loss relative to a specified range using subroutine CURVE. The X's represent input data points. R_1 is less than the minimum input range, so L_1 is determined by extending the first line segment. R_2 is within the convergence zone.

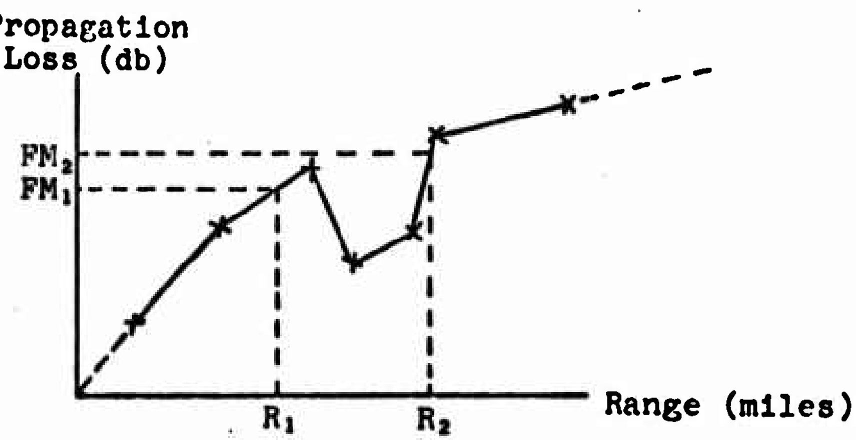


Figure 12. Examples of estimating detection range based on ship noise characteristics. FM_1 and FM_2 are figures of merit for different ship speeds. The detection range is the minimum distance associated with each figure of merit.

list is searched for the smallest valued entry. This entry and its corresponding event type are exchanged with the entries which have index value 1. The procedure is repeated for each index until the ordering is complete.

Entry ORDER2: This routine places the time of the next execution of the event type currently being processed in its proper sequence in the event calendar. In this case the new event time is located in its proper order and the indices of all unexecuted events with earlier times are reduced by one.

Entry ORDER3: This section arranges the time of a rescheduled event in its proper sequence in the calendar. The event is located in its proper sequence and adjusts the intervening times one place up or down as the revised time is earlier or later.

PIM: Attacker course and time to intercept the target are computed based on intelligence data each time the attacker receives new intelligence, either through a CZ event or communications event. The intercept time, T, is found by simultaneously solving the equations

$$S_y T + Y = V_y T$$

$$S_x T + X = V_x T$$

$$V_x^2 + V_y^2 = V$$

where S_x and S_y are the intelligence velocity components, V_x and V_y are the (unknown) components of attacker velocity, V, and X and Y are the component differences between the attacker and intelligence positions. If a real, non-negative solution exists the intercept coordinates are determined and subroutine COURSE is called to find the intercept course.

RAD: This routine converts angles in degrees to radians.

DEG: This routine converts radians to degrees.

COURSE: The resultant direction of two component vectors is found by this routine using the FORTRAN library routine ATAN.

REVENT: This routine generates random intelligence times for each leg of the target track. A random number, R, is selected by the random number generator and compared with the probability of an intelligence detection, P_i, associated with target track leg i. This comparison is repeated for each successive interval of specified duration, t. When R is less than P_i the time of detection is given by $T = T_s + tR/P_i$, where T_s is the initial time of the interval.

RNG: The random number generator selects a random number from a uniform distribution between zero and one. This routine is related to the machine configuration and must be rewritten for computers other than the IBM 360.

NORMAL: This routine is used to generate random numbers from a normal distribution using the principal that the sum of indepentent random variables tends to a normal distribution with mean equal to the sum of the means and variance equal to the sum of the variances. Twelve random numbers generated by RNG are added to -6 to approximate a normal distribution with zero mean and unit variance.

RAND: A random number, D, is selected uniformly over the interval minus one to one using a random number, R, generated by RNG according to the formula D = 2(R-0.5).

SPCL: SPCL is a blank evasion subroutine which may be programmed by the user to introduce revised evasion tactics or assemble additional evasion statistics. The calling sequence is included in the program and controlled by input.

FORTRAN library routines: Five subprograms from the FORTRAN library are used by VIM:

SIN: This routine computes the trigonometric sine of an angle given in radians.

COS: This routine computes the trigonometric cosine of an angle given in radians.

ATAN: This routine computes the angle in radians whose tangent is the calling argument.

SQRT: This routine computes the square root of a non-negative number.

IBCOM: This routine controls the input and output functions of the computer system.

IV. INPUT / OUTPUT

A large proportion of VIM is devoted to input of the required data, assembly of statistics and information display. This chapter is a discussion of the details of the input and output routines including the simplified input of successive runs and options available for controlling the level of output detail.

A. DATA INPUT

Input data is treated in six groups: environmental, identification, option, situation, target track and intelligence. This section outlines the input requirements for each data group when executing a series of runs.

Environmental data: Only one set of environmental data may be applied to a series of runs. The data must be entered prior to the first run and remains unchanged throughout the series.

Run identification data: The run identification number and description must be included with each run. Provision is made in this group to initiate changes to the option and situation data.

Option data and situation data: Complete sets of option data and situation data must be included preliminary to the first run. Either group may be altered between runs, totally revised or left completely unchanged. Once a change has been entered the new value is retained indefinitely.

Target track data: A complete target track must be included in the data set for the first run. The target track may be totally revised between runs or repeated in unaltered form.

Intelligence data: Intelligence data may be omitted from all runs or included with any of the run data sets. Input data may be carried over from run to run as long as a random intelligence option is not used.

B. OUTPUT

Several levels of output are available to provide for a careful verification of program operation, to provide access to data the analysis of which was not anticipated by the design of VIM and to permit efficient computer usage when the above factors are not dominant. There are three output categories: trial history, trial summary and run summary. The trial history and summary may be included with the output or deleted. The run summary will always be included but may be displayed in an abridged form.

Trial history: The detailed trial history provides a list of each event of the trial with all amplifying data. Each event is characterized by the event time and a brief description of the event type followed by the current status of detection probability, courses, speeds, range and tactical situation along with any special information which might apply to the particular event. The trial history may be required for the first trial only, all trials or omitted entirely. The trial history adds from one to two seconds of execution time for each trial and adds one output page for each five events.

Trial summary: The trial summary is a list of the detection probabilities established during the trial with the associated detection times and the status of the attacker (transiting or on search station) at each detection event. The trial summaries may be displayed with each trial history, in place of each trial history, or be omitted entirely. When appearing in place of the trial histories one page of output is required for each trial.

Run summary: The run summary is a compilation of the individual trial results of some of the significant statistics along with the mean and variance of each set of statistics. The individual trial results may be omitted.

C. DETAILED DESCRIPTION OF OUTPUT

VIM output includes a display of the input data used for the experiment followed by the information generated during the run in the form of trial history, trial summary and sun summary.

1. Input Data Display (Figure 13)

All input data is displayed at the beginning of each run regardless of the output or input options. The data groups shown on the sample input display, Figure 13, are explained in the following paragraphs.

The self and radiated noise curves for the attacker and target are each approximated by six linear segments.

```
                    DATA SET    101    TRIAL       1    PAGE       1

INPUT DATA SET    101

ENVIRONMENTAL DATA

SAMPLE DATA SET WITH CONVERGENCE ZONE ( PREPARED FOR VIM USERS MANUAL )

ATTACKER NOISE CURVES
      0.0        3.00       10.00       15.00       22.00       25.00       32.00
   -45.00      -40.00      -30.00      -22.00      -12.00       -7.00        0.0
     3.00        9.00       17.00       24.00       34.00       36.00       42.00

TARGET NOISE CURVES
      0.0        5.00       10.00       15.00       20.00       25.00       30.00
   -33.00      -28.00      -22.00      -17.00      -11.00       -6.00        0.0
    12.00       12.00       13.00       17.00       23.00       32.00       42.00

PROPAGATION LOSS CURVE
    75.00       92.00      100.00       85.00       90.00      115.00      127.00
     5.00       17.00       30.00       35.00       45.00       50.00      100.00
```

Figure 13. Input Data Display

```
FIRST SAMPLE RUN- RAND TARG TRK, TRIAL HIST, TRIAL SUM, INPUT INTEL, CZ INTEL

 OPTION INPUTS

NTRIAL =   7    M =  2    N =    3    IOPT =  2    NOPT =  0    NCYCR =      597321
   NEVD =  4    NCOMP =   4    INRAND =  1    NC =  0    NSUP =  0    NRTT =  1 ICZ =  1

 SITUATION INPUTS

TEND =  48.00    CINT =  0.0     XTI =      0.0     YTI =  500.00    TL = 1.20
   TINT = 4.00     ETIME =    2.50

SS = 13.00    SA = 20.00    VI =  0.10    CAI =   0.0    SI =  2.50
   AMB = -42.00    SIGMA = 9.00

EVANG =  60.00    EVSPD =  -3.00    SE =  3.00    CE = 30.00    SAF = 3.50
   GAINA = 36.00    GAINT = 34.00

 CZR =  40.00  CZW =   7.00  CZSE =   4.00  CZCE =  15.00  CZBE =   2.50
 CZRE =   5.00
```

TARGET TRACKS

CST	SPT	TT	PINT	SPAX	SPAY
180.00	16.00	0.10	0.0	100.00	0.0
180.00	16.00	200.00	25.00	25.00	25.00

INTELLIGENCE TIMES

TI	RINP	BINP	CINP	SINP
1.00	13.00	25.00	168.00	13.00
22.50	21.00	84.00	195.00	18.00
47.00	9.00	156.00	174.00	17.00

The first row of each of the noise tables is a list of the ship speeds for which noise estimates are to be provided. The second row represents the radiated noise in decibels at the respective speeds. The third row represents the self noise in decibels at the speeds listed in the first row.

The propagation loss curve is also approximated by six linear segments. The top row of the table is the propagation loss in decibels associated with each of the ranges in miles listed in the second row.

The input value of each option and situation variable is listed with the variable name. Each pair of printed lines displays the entries from a single input data card.

The proposed target track is displayed as a sequence of rows, each row specifying the data associated with each successive leg. The variable names are listed at the top of each column.

Intelligence data input by the user will be displayed as a sequence of rows, each row specifying the data associated with a particular intelligence detection. The variable names are listed at the top of each column. If intelligence times are determined randomly the times for the first trial will appear in rows of seven columns. Intelligence times generated randomly for subsequent trials will be displayed following the trial summary.

2. Detailed Trial History (Figure 14)

The trial history is sequence of messages that describe the state of the trial at each event. The

```
                    DATA SET   101   TRIAL     1   PAGE     2

COMMENCE TRIAL   1

                    ATTACKER COURSE =    0.0 SPEED =  0.1
                      TARGET COURSE = 172.2 SPEED =  15.8
                    TARGET COORDINATES       -8.14    500.00
                    RANGE = 500.07 MILES

PROBLEM TIME =   0.10    NEW TARGET LEG
                    CURRENT INTELLIGENCE TIME =    0.0
                    EXPECTED CPA TIME =   29.92
                    CURRENT PROBABILITY OF DETECTION  0.0
                    CUMULATIVE PROBABILITY OF DETECTION  0.0
                    ATTACKER NOT ON STATION
                    ATTACKER COURSE =    0.0 SPEED =  0.1
                      TARGET COURSE = 178.1 SPEED =  16.6
                    TARGET COORDINATES       -7.93    498.43
                    ATTACKER CORDINATES        0.0        0.01
                    RANGE = 498.49 MILES

PROBLEM TIME =   1.00    INTEL. DETECTION
                    INTELLIGENCE DATA - POSIT     -1.93    495.27
                                         COURSE  168.00  SPEED13.00 KTS.
                    CURRENT INTELLIGENCE TIME =   0.0
                    EXPECTED CPA TIME =   29.92
                    CURRENT PROBABILITY OF DETECTION  0.0
                    CUMULATIVE PROBABILITY OF DETECTION  0.0
                    ATTACKER NOT ON STATION
                    ATTACKER COURSE =    0.0 SPEED =  0.1
                      TARGET COURSE = 178.1 SPEED =  16.6
                    TARGET COORDINATES       -7.42    483.49
                    ATTACKER CORDINATES        0.0        0.10
                    RANGE = 483.45 MILES
```

Figure 14. Detailed Trial History

```
PROBLEM TIME =   2.20    ATTACKER COMM. PERIOD
          CURRENT INTELLIGENCE TIME =   1.00
          EXPECTED CPA TIME =  14.87
          CURRENT PROBABILITY OF DETECTION  0.0
          CUMULATIVE PROBABILITY OF DETECTION  0.0
          ATTACKER RECEIVES LATEST INTELLIGENCE
          UPDATED INTELLIGENCE COORDINATES        1.31    480.01
                               COURSE  168.00 SPEED 13.00 KTS
          ATTACKER NOT ON STATION
          ATTACKER COURSE =    8.0 SPEED = 20.0
            TARGET COURSE = 178.1 SPEED =  16.6
          TARGET COORDINATES        -6.75    463.56
          ATTACKER CORDINATES         0.0        0.22
          RANGE = 463.39 MILES

PROBLEM TIME =  14.34  CONVERGENCE ZONE EVENT
          CURRENT INTELLIGENCE TIME =   1.00
          EXPECTED CPA TIME =  14.87
          CURRENT PROBABILITY OF DETECTION  0.025
          CUMULATIVE PROBABILITY OF DETECTION  0.0
          ATTACKER NOT ON STATION
          ATTACKER COURSE =    0.0 SPEED = 20.0
            TARGET COURSE = 178.1 SPEED =  16.6
          TARGET COORDINATES         0.08    261.99
          ATTACKER CORDINATES        33.89    240.62
          RANGE =  40.00 MILES

PROBLEM TIME =  16.95    NEW ATTACKER LEG
          CURRENT INTEL. TIME =   1.00
             RANGE OPENING
          CURRENT PROBABILITY OF DETECTION  0.0
          CUMULATIVE PROBABILITY OF DETECTION  0.0
          ATTACKER ON STATION
          ATTACKER COURSE = 258.0 SPEED = 13.0
            TARGET COURSE = 178.1 SPEED =  16.6
          TARGET COORDINATES         1.55    218.57
          ATTACKER CORDINATES        41.19    292.40
          RANGE =  83.80 MILES
```

```
PROBLEM TIME =  18.20    NEW ATTACKER LEG
                   CURRENT INTEL. TIME =     1.00
                      RANGE OPENING
                   CURRENT PROBABILITY OF DETECTION  0.0
                   CUMULATIVE PROBABILITY OF DETECTION  0.0
                   ATTACKER ON STATION
                   ATTACKER COURSE =  78.0 SPEED = 13.0
                     TARGET COURSE = 178.1 SPEED =  16.6
                   TARGET COORDINATES        2.25    197.81
                   ATTACKER CORDINATES       25.29     289.03
                   RANGE =  94.08 MILES

PROBLEM TIME =  20.70    NEW ATTACKER LEG
                   CURRENT INTEL. TIME =     1.00
                      RANGE OPENING
                   CURRENT PROBABILITY OF DETECTION  0.0
                   CUMULATIVE PROBABILITY OF DETECTION  0.0
                   ATTACKER ON STATION
                   ATTACKER COURSE = 256.0 SPEED = 13.0
                     TARGET COURSE = 178.1 SPEED =  16.6
                   TARGET COORDINATES        3.66    156.30
                   ATTACKER CORDINATES       57.08     295.78
                   RANGE = 149.37 MILES

PROBLEM TIME =  22.50    INTEL. DETECTION
                   INTELLIGENCE DATA - POSIT       25.55     128.67
                                        COURSE  195.00   SPEED18.00 KTS.
                   CURRENT INTEL. TIME =     1.00
                      RANGE OPENING
                   CURRENT PROBABILITY OF DETECTION  0.0
                   CUMULATIVE PROBABILITY OF DETECTION  0.0
                   ATTACKER ON STATION
                   ATTACKER COURSE = 258.0 SPEED = 13.0
                     TARGET COURSE = 178.1 SPEED =  16.6
                   TARGET COORDINATES        4.67    126.47
                   ATTACKER CORDINATES       34.24     290.93
                   RANGE = 167.10 MILES

PROBLEM TIME =  41.69   POSSIBLE DETECTION OF TARGET
                   CURRENT INTEL. TIME =  22.50
                      RANGE OPENING
                   CURRENT PROBABILITY OF DETECTION  0.0
                   CUMULATIVE PROBABILITY OF DETECTION  0.0
                   ATTACKER NOT ON STATION
                   ATTACKER COURSE = 193.9 SPEED = 20.0
                     TARGET COURSE = 178.1 SPEED =  16.6
                   TARGET COORDINATES       15.46   -192.27
                   ATTACKER CORDINATES      -54.56     -59.06
                   RANGE = 150.49 MILES
```

```
                    DATA SET   101   TRIAL     1   PAGE     5

PROBLEM TIME =  74.12  CONVERGENCE ZONE EVENT
                  CURRENT INTELLIGENCE TIME =   0.0
                  EXPECTED CPA TIME =  79.44
                  CURRENT PROBABILITY OF DETECTION  0.025
                  CUMULATIVE PROBABILITY OF DETECTION  0.0
                  ATTACKER RECEIVES LATEST INTELLIGENCE
                  UPDATED INTELLIGENCE COORDINATES      33.75   -730.10
                                       COURSE  187.31 SPEED 18.96 KTS
                  ATTACKER NOT ON STATION
                  ATTACKER COURSE = 185.9 SPEED = 20.0
                    TARGET COURSE = 178.1 SPEED =  16.6
                  TARGET COORDINATES      33.69   -730.76
                  ATTACKER CORDINATES       21.72   -692.60
                  RANGE =  43.30 MILES

PROBLEM TIME = 114.72    END OF TRIAL   1
                  CURRENT INTEL. TIME =   0.0
                     RANGE OPENING
                  CURRENT PROBABILITY OF DETECTION  0.0
                  CUMULATIVE PROBABILITY OF DETECTION  0.0
                  ATTACKER ON STATION
                  ATTACKER COURSE = 277.3 SPEED = 13.0
                    TARGET COURSE = 178.1 SPEED =  16.6
                  TARGET COORDINATES      56.52  -1404.85
                  ATTACKER CORDINATES      -65.24  -1373.75
                  RANGE = 125.67 MILES

          END OF TRIAL SUMMARY OF DETECTION PROBABILITIES - TRIAL     1

                  CUMULATIVE PROBABILITY OF DETECTION  0.0

  NO POSITIVE DETECTION PROBABILITIES ESTABLISHED

NCYCR = 1736090979
```

following paragraphs explain the messages found in the trial history.

Event definition message: This message provides the problem time of the event and a descriptive phrase identifying the event type. The event definition messages are self explanatory and refer to the events described in Chapter III, Section B. Following each event definition is a series of status messages which are explained below.

INTELLIGENCE DATA: The estimate of target position, course and speed generated by a surveillance system detection.

CURRENT INTELLIGENCE TIME: The time of the latest surveillance intelligence provided to the attacker. If the most recent intelligence is the result of a CZ detection the time printed is zero.

EXPECTED CPA TIME: The expected time of CPA based on current course and speed is listed if the range between the ships is decreasing.

RANGE OPENING: The range between the units is increasing.

CURRENT PROBABILITY OF DETECTION: The sonar equation estimate of detection probability based on current range and speeds. If a speed change by either ship has occured during this event the greater probability based on the speeds before and after execution of the event is listed. The probability shown will not be included in the cumulative trial estimate if the attacker is on search station.

CUMULATIVE PROBABILITY OF DETECTION: The aggregate probability of detection as described in Chapter III, Section A. Note that if the attacker is on search station cumulative detection probability will not change until new intelligence is received or the trial is terminated at which time the maximum probability generated during the search period will be used to update the trial estimate.

ATTACKER RECEIVES LATEST INTELLIGENCE: New intelligence has become available to the attacker during a Communications event or CZ event.

UPDATED INTELLIGENCE COORDINATES: Intelligence data being released to the attacker at a communications period is updated to the current time based on the course and speed estimates. If the message accompanies a convergence zone event the values given represent the current estimates of a CZ intelligence detection.

ATTACKER NOT ON STATION: Attacker is awaiting its first intelligence information or has not yet reached the projected intercept point in response to intelligence data.

ATTACKER ON STATION: Attacker is on search station as determined by the most recently received intelligence.

ATTACKER COURSE: Self explanatory

TARGET COURSE: Self explanatory

TARGET COORDINATES: Self explanatory

ATTACKER COORDINATES: Self explanatory

3. Trial Summary (Figure 15)

In addition to the cumulative detection probability for the trial, each estimated probability with its corresponding time is listed. The first group of numbers represents the times at which a detection probability was estimated while the attacker was in transit. Zero's are inserted as space keepers. The third group of numbers is a list of the times at which a detection probability was estimated while the attacker was on search station. Again, zero's are inserted as spacers. Sandwiched between the two lists are the probability estimates which correspond to the times listed above and below. The time of each estimate is the non-zero entry in one of the two time lists.

The random number seed, NCYCR, in effect at the end of the trial is listed. This number may be used in the duplication of the next trial.

4. Run Summary (Figure 16)

The run summary lists the data accumulated over a series of trials. The following information is provided to clarify the messages and descriptive titles appearing in the run summary:

OPTIMAL TARGET INTERCEPT: The time and position provided with this message represent the intercept time and location that would be generated if the attacker knew the target course and speed on each leg and was able to observe each course change.

Figure 15. Trial Summary

```
DATA SET    101    TRIAL     3    PAGE     9


COMMENCE TRIAL    4

        ATTACKER COURSE =    0.0 SPEED =  0.1
          TARGET COURSE = 159.1 SPEED =  14.7
        TARGET COORDINATES      -64.37   500.00
        RANGE = 504.13 MILES

PROBLEM TIME =  74.96    END OF TRIAL    4

      END OF TRIAL SUMMARY OF DETECTION PROBABILITIES - TRIAL     4

          CUMULATIVE PROBABILITY OF DETECTION  0.147
  TRANSIT PROBABILITY TIMES
 15.64    0.0
 ESTABLISHED PROBABILITIES
  0.07    0.08
 ON STATION PROBABILITY TIMES
  0.0    23.70

NCYCR = 1452704771
```

DATA SET 101 TRIAL 7 PAGE 13

END OF GAME.
TOTAL OF 7 TRIALS

DATA SET 101 SUMMARY

INITIAL RANGE TO TARGET 500.00 MILES

OPTIMAL TARGET INTERCEPT UNDER PERFECT INFORMATION
TIME 13.89 POSIT -0.00 277.78

COUNTERDETECTIONS OF ATTACKER BY TARGET EACH TRIAL

DURING TRANSIT

0	0	0	1	0	0	1

SAMPLE MEAN = 0.286 SAMPLE VARIANCE = 0.238

DURING SEARCH

0	0	0	0	0	0	0

SAMPLE MEAN = 0.0 SAMPLE VARIANCE = 0.0

TOTAL

0	0	0	1	0	0	1

SAMPLE MEAN = 0.286 SAMPLE VARIANCE = 0.238

TIMES TO END TRIAL

114.72	55.04	112.08	74.96	114.60	89.53	75.99

SAMPLE MEAN = 90.989 SAMPLE VARIANCE = 556.875

CUMULATIVE PROBABILITIES EACH TRIAL

0.0	0.15	0.0	0.15	0.0	0.0	0.15

SAMPLE MEAN = 0.064 SAMPLE VARIANCE = 0.006

CUMULATIVE TRANSIT PROBABILITIES EACH TRIAL

0.0	0.0	0.0	0.07	0.0	0.0	0.03

SAMPLE MEAN = 0.014 SAMPLE VARIANCE = 0.001

CUMULATIVE STATION PROBABILITIES EACH TRIAL

0.0	0.15	0.0	0.08	0.0	0.0	0.12

SAMPLE MEAN = 0.051 SAMPLE VARIANCE = 0.004

Figure 16. Run Summary

```
THE FOLLOWING DATA APLIES TO THE TIME OF MAXIMUM OBSERVED PROBABILITY

   NUMBER OF OCCURENCES OF MAXIMUMDETECTION PROBABILITY DURING:

      TRANSIT     0
         SEARCH     3
         EVASION    0

    MAXIMUM DETECTION PROBABILITIES
     0.0        0.15        0.0        0.08        0.0        0.0        0.12

        SAMPLE MEAN =    0.051         SAMPLE VARIANCE =      0.004

    MAXIMUM SEARCH PROBABILITIES
     0.0        0.15        0.0        0.08        0.0        0.0        0.12

        SAMPLE MEAN =    0.051         SAMPLE VARIANCE =      0.004

   MAXIMUM TRANSIT PROBABILITIES
     0.0        0.0         0.0        0.07        0.0        0.0        0.03

        SAMPLE MEAN =    0.014         SAMPLE VARIANCE =      0.001

   TIMES OF MAXIMUM DETECTION PROBABILITIES

     0.0       51.29        0.0       23.70        0.0        0.0       23.70

        SAMPLE MEAN =   32.898         SAMPLE VARIANCE =    253.817

 TOTAL POSITIVE ENTRIES     3
   TIMES OF LAST BROADCAST BEFORE MAXPROBABILITIES
     0.0       48.20        0.0        2.20        0.0        0.0        2.20

        SAMPLE MEAN =   17.533         SAMPLE VARIANCE =    705.333

 TOTAL POSITIVE ENTRIES     3

   ACQUISITION TIMES OF INTELLIGENCE LEADING TO MAXIMUM PROBABILITIES

     0.0       47.00        0.0        1.00        0.0        0.0        1.00

        SAMPLE MEAN =   16.333         SAMPLE VARIANCE =    705.333

 TOTAL POSITIVE ENTRIES     3

   DELAYS FROM ACQUISITION TO BROADCAST
     0.0        1.20        0.0        1.20        0.0        0.0        1.20

        SAMPLE MEAN =    1.200         SAMPLE VARIANCE =     -0.000

 TOTAL POSITIVE ENTRIES     3

   DELAYS FROM BROADCAST TO MAXIMUM PROBILITIES

     0.0        3.09        0.0       14.73        0.0        0.0       14.86

        SAMPLE MEAN =   10.895         SAMPLE VARIANCE =     45.648

 TOTAL POSITIVE ENTRIES     3

 CONVERGENCE ZONE DETECTION TIMES
   74.12       0.0         0.0        0.0         0.0        0.0        0.0
```

SAMPLE MEAN: The arithmetic average and sample variance of each category based on the trial results is printed under this heading. When the run summary is suppressed the sample mean and variance only are printed under each heading.

COUNTERDETECTIONS: A list of the number of counterdetections each trial, arranged according to the status of the attacker, is presented under this title. The first list is the number of times the attacker was detected during transit, then the number of counterdetections while attacker is on search station and, finally, the total number of counterdetections. These lists are omitted if no evasion is ordered.

TIMES TO END TRIAL: A list of the termination time of each trial.

CUMULATIVE PROBABILITIES: A list of the cumulative probabilities generated each trial, both overall and according to the attacker status.

NUMBER OF OCCURENCES OF MAXIMUM DETECTION PROBABILITY: A count of the number of trials in which the maximum detection probability was generated during target evasion, attacker transit and attacker search.

MAXIMUM DETECTION (SEARCH, TRANSIT) PROBABILITIES: A list of the maximum detection probabilities achieved each trial, both overall and according to attacker status.

TIMES OF LAST BROADCAST: A list of times of receipt of the surveillance intelligence data which preceded the maximum detection probability for each trial. Zero's appear for each trial in which the maximum detection probability was zero or was preceded by a CZ intelligence detection.

ACQUISITION TIMES: The times of the surveillance intelligence data preceding the maximum detection probability estimates for each trial are listed. If a CZ intelligence detection preceded the maximum probability, or if the maximum probability was zero, a zero entry is printed.

DELAYS FROM ACQUISITION: The delay from intelligence acquisition time until broadcast of the final surveillance intelligence preceding the maximum detection probability for each trial is listed. If a CZ intelligence detection preceded the maximum probability, or if it was zero, a zero entry is printed.

CONVERGENCE ZONE INTELLIGENCE TIMES: A list of times of convergence zone intelligence detections preceding the maximum probability of detection. Zero's appear for trials in which the maximum detection probability was zero or followed a surveillance detection. If CZ intelligence is not permitted, this table lists the trial times of CZ detection probability estimates which were trial maximums.

5. Special Messages

The following messages are printed to indicate possible abnormal response to the input data. Each message must be interpreted in light of the problem being run.

UNABLE TO OVERTAKE TARGET DUE TO SPEED DIFFERENTIAL. ABORT TRIAL N: The course speed and position estimate upon which the attacker must base its transit path are such that an intercept is impossible, and no further surveillance intelligence will become available during the trial. This message is suppressed when the run summary is suppressed.

INTELLIGENCE TIME OPTION (NOPT) AND INTELLIGENCE COMPUTATION OPTION (NCOMP) ARE INCOMPATIBLE. ABORT RUN K: An attempt has been made to combine random intelligence times with input intelligence estimates. The run with identification number K was aborted and the next run executed. The option inputs controlling intelligence should be checked.

SONAR EQUATION PARAMETERS EXCEED INPUT LIMITS. DATA EXTRAPOLATION FOR (ATTACKER SPEED, TARGET SPEED, PROPAGATION LOSS) X: The noise or propagation loss curve was not explicitly defined for the value X. A linear extrapolation has been performed based on the two data points nearest X. This message appears only with the detailed trial history.

V. USER'S MANUAL

The objective of this chapter is to provide a user of VIM with all the information necessary to conduct an experiment with the simulation. Section A describes the inputs in detail with cross referencing to pertinent sections of the thesis as well as to other input variables for which a relationship exists. Tables 2 through 8 provide an input guide for the experienced user containing only brief definitions and no cross referencing. Section C describes the assembly of a complete data deck in detail.

References to inputs in this chapter will be of the form NAME, XX-N, where NAME is the designation of the input variable, XX is the input category, and N is the serial number of the input within the category. The input designations and categories are

EC - Environmental curve,

RI - Run identification,

OD - Option data,

SD - Situation data,

TD - Track data, and

ID - Intelligence data.

A. DETAILED DESCRIPTION OF INPUTS

This section lists each input parameter to VIM by category, and includes the key punching instructions and complete definition. The relationship of each parameter to other input variables and its function in the simulation is discussed. The column headings found in the input lists are number, name, card field, units, limits and description. "Number" is the serial number of the input within its category. "Name" is the designation of the variable within the program. "Card" is the sequence number of the card within the input category. "Units" refers to the dimension of the variable: miles (mls), hours (hrs), knots (kts), decibels (db) or degrees (deg). "Limits" defines the range of permissible values which may be assigned. If "pos" appears under "limits," the variable must be assigned a positive value. If "non-neg" is listed, a positive or zero value must be assigned. In some cases the limits are determined by the values assigned to other input variables. "Description" includes the variable definition and amplifying remarks. Columns which do not apply to a particular input category are omitted.

1. Environmental Data Cards

The environmental data group consists of a title card in which the user is free to enter any message for reproduction on the input data display, a group of three attacker noise cards, a group of three target noise cards and a pair of propagation loss cards. Except for the title card each card is divided into seven fields of ten columns each. One entry must be included in each field with a decimal point in the appropriate location. Each entry is indexed according to the position of its field on the card.

The entries in the card groups represent point approximations of the noise curves. Figures 17 and 18 are examples of an attacker radiated noise curve and a propagation loss curve with the input values indicated. Figure 13 shows the input display of these curves. Interpretation and use of the input data points is described in Chapter III, Section A under detection, and Chapter III, Section C under DETECT. Interpolation between pairs of data points is accomplished by subroutine CURVE. One environmental data group must be included with each series of runs. The environmental data is summarized in Table II.

Title card: The title card is the first card of the data set. It may be blank, but must be included.

Field	Description
2-80	Any title, date or descriptive message.

Attacker noise curves:

Name	Field	Units	Description
VN(1)	1-10	kts	Attacker speed card. Each entry is a speed for which attacker self and radiated noise must be estimated. Each speed listed should be greater than the preceding speed. Entries on the attacker self noise and radiated noise cards must correspond to the entries on this card.
VN(2)	11-20		
VN(3)	21-30		
VN(4)	31-40		
VN(5)	41-50		
VN(6)	51-60		
VN(7)	61-70		
SNA(1)	1-10	db	Attacker self noise card. Entries represent the self noise generated at the speeds listed on the attacker speed card.
SNA(2)	11-20		
SNA(3)	21-30		
SNA(4)	31-40		
SNA(5)	41-50		
SNA(6)	51-60		
SNA(7)	61-70		

Figure 17. Example of attacker radiated noise curve approximation. The numbers on the horizontal and verticle axes represent the points on which the approximation is based. See Figures 13 and 20.

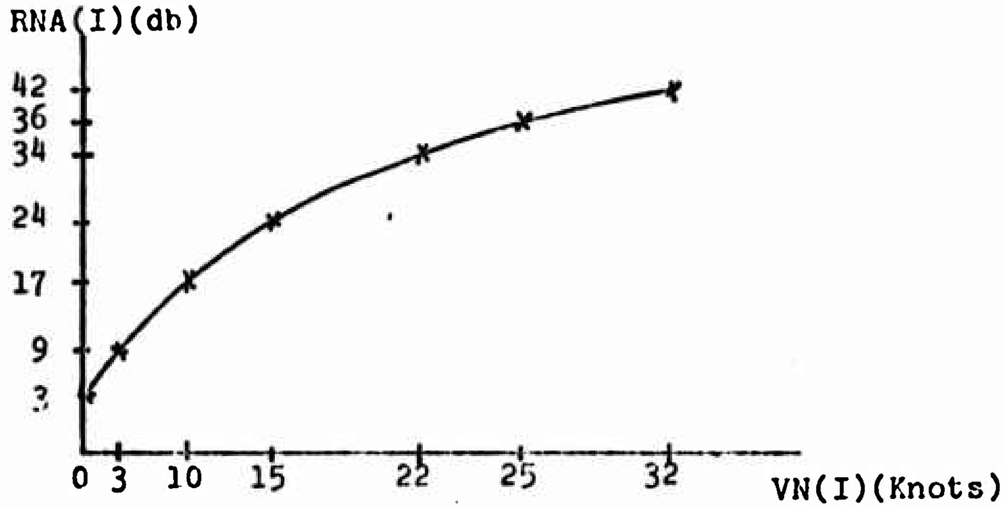
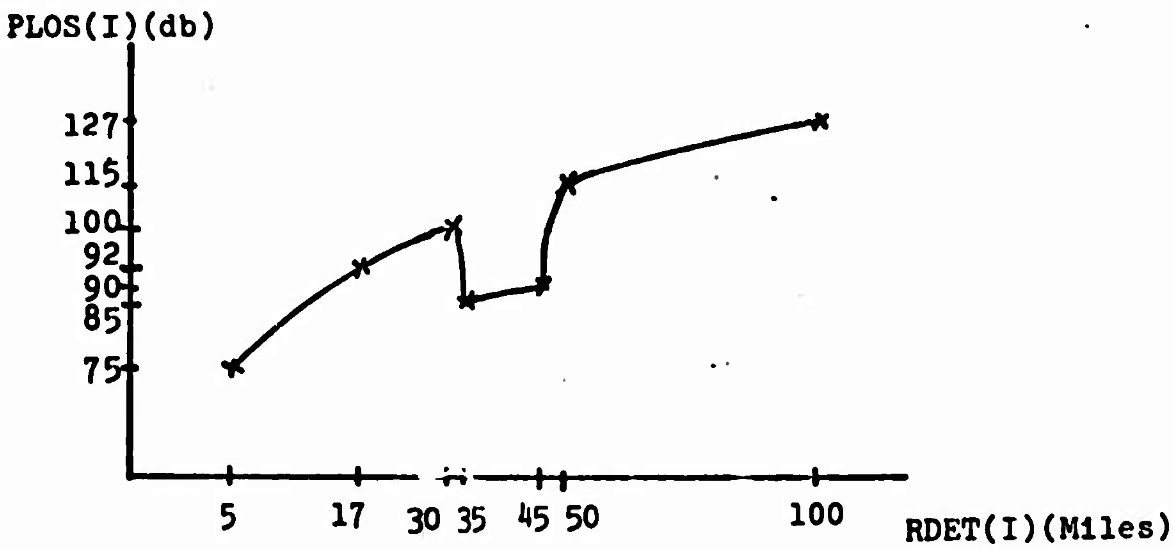


Figure 18. Example of Propagation loss curve with convergence zone. The numbers on the horizontal and verticle axes represent the points on which the approximation is based. See Figures 13 and 20.



Name	Field	Units	Description
RNA(1)	1-10	db	Attacker radiated noise card. Entries represent the noise radiated by the attacker at the speeds listed on the attacker speed card.
RNA(2)	11-20		
RNA(3)	21-30		
RNA(4)	31-40		
RNA(5)	41-50		
RNA(6)	51-60		
RNA(7)	61-70		

Target noise curves:

Name	Field	Units	Description
STN(1)	1-10	kts	Target speed card. Each entry is a speed for which target self and radiated noise must be estimated. Each speed listed should be greater than the preceding speed. Entries on the target self noise and radiated noise cards must correspond to the entries on this card.
STN(2)	11-20		
STN(3)	21-30		
STN(4)	31-40		
STN(5)	41-50		
STN(6)	51-60		
STN(7)	61-70		
SNT(1)	1-10	db	Target self noise card. Entries represent the self noise generated at the speeds listed on the target speed card.
SNT(2)	11-20		
SNT(3)	21-30		
SNT(4)	31-40		
SNT(5)	41-50		
SNT(6)	51-60		
SNT(7)	61-70		
RNT(1)	1-10	db	Target radiated noise card. Entries represent the noise radiated by the target at the speeds listed on the target speed card.
RNT(2)	11-20		
RNT(3)	21-30		
RNT(4)	31-40		
RNT(5)	41-50		
RNT(6)	51-60		
RNT(7)	61-70		

Propagation loss curve:

Name	Field	Units	Description
PLOS(1)	1-10	db	Propagation loss card. Entries represent the reduction in noise level at the distances from the noise source listed on the range card. No restrictions are placed on the relative size of the entries, but decreasing entries associated with a convergence zone will result in jump increases in counterdetection range at the point of decrease. See Figure 12.
PLOS(2)	11-20		
PLOS(3)	21-30		
PLOS(4)	31-40		
PLOS(5)	41-50		
PLOS(6)	51-60		
PLOS(7)	61-70		

Name	Field	Units	Description
RDET(1)	1-10	mls	Range curve. Entries represent the distance from the noise source associated with each entry on the propagation loss card. Entries should be increasing.
RDET(2)	11-20		
RDET(3)	21-30		
RDET(4)	31-40		
RDET(5)	41-50		
RDET(6)	51-60		
RDET(7)	61-70		

2. Run Identification Cards

The run identification cards must be included with each run of a series of runs. The first card is the run number card with one to four integer entries which must be right adjusted in their fields, and contain no decimals. The second card is the run description card. The run identification cards are summarized in Table III.

Run number card:

No.	Name	Field	Description
1	NUMBER	1-5	An arbitrary run identification number assigned by the user. NUMBER is printed with the input data display, the run summary and at the top of each page of output.
2	NCYCR	6-15	Random number seed. This entry is blank on the first run of a series of runs, and whenever a new option data card is included with the run data. In that event, NOC, RI-3, is zero or blank and NCYCR is entered as OD-6.
3	NC	16-20	Number of option changes this run. This entry is zero or blank on the first run and whenever a new option data card is included with the run data. If NOC has the value one through 13, option change cards specifying NOC changes to the option data are required. If no change to the option data is desired set NOC to 99 and omit option data and option change cards.

No.	Name	Field	Description
4	NC	21-25	Number of situation changes this run. This entry must be zero or blank on the first run and whenever a new set of situation data is to be entered. If NC has the value one through 27, situation change cards specifying NC changes to the situation data are required. If no change to the situation data is desired set NC to 99 and omit situation data and situation change cards. When the option data card is to be included with the data set NC is entered as OD-10.

Run description card: The run description card contains alphabetic and numeric information or may be blank but must be included with the data set for each run.

Field	Description
2-80	A date, title or descriptive message regarding the run.

3. Option Data Cards

The option data card must accompany the first run data set and may be omitted, replaced by option change cards or included with subsequent data sets. All inputs are integer and must be right adjusted within the specified field. An option input card must be included whenever NOC, RI-3, is zero or blank. The option data inputs are summarized in Table IV.

No.	Name	Field	Limits	Description
1	NTRIAL	1-5	1-100	Number of trials for this run. Chapter VI, Section A includes a discussion of determining the magnitude of NTRIAL.

No.	Name	Field	Limits	Description
2	M	6-10	0-50	The number of target track cards included with the data set for this run. If M is zero the target track from the previous run will be used.
3	N	11-15	0-100	The number of intelligence detections to be input for this run. If N is zero intelligence detection times will be taken from the previous run or computed randomly per NOPT, OD-5.
4	IOPT	16-20	1-5	Level of output detail. See Chapter V, Sections B and C for further discussion. The run summary is included with all output options. IOPT=1: Detailed history of each trial including the end of trial summary. If random intelligence times are computed for each trial (NOPT, OD-5) they are printed at the start of each trial. IOPT=2: Detailed history of first trial. End of trial summary for each trial. If random intelligence times are computed for each trial (NOPT, OD-5) they are printed preceding the trial summary display. IOPT=3: End of trial summary for each trial. If random intelligence times are computed before each trial (NOPT, OD-5) they are printed preceding the trial summary display. IOPT=4: Detailed history of the first trial only. IOPT=5: End of run summary only.
5	NOPT	21-25	-1,0,1	Intelligence time option switch. Table I summarizes the values of NOPT, NCOMP (OD-8) and INRAND (OD-9) for each of the permissible intelligence combinations.

No.	Name	Field	Limits	Description
	NOPT (cont.)			NOPT=-1: Intelligence detection times will be selected randomly before each trial according to the parameters TINT, SD-6, and PINT, TD-4. Under this option N, OD-3, must be zero and NCOMP, OD-8, must be one or two. Omit the intelligence data cards. NOPT=0: Intelligence detection times will be taken from the intelligence data cards. Set N, OD-3, to the number of intelligence times desired and include N intelligence data cards. NOPT=1: Intelligence detection times will be selected randomly for the first trial according to the parameters TINT, SD-6, and PINT, TD-4. Subsequent trials will use the same intelligence times. Under this option N, OD-3, must be zero and NCOMP, OD-8, must be one or two. Omit the intelligence data cards.
6	NCYCR	26-35	$1-10^{10}$	Random number seed. NCYCR is the first random number used by subroutine RNG in generating a sequence of random numbers. RNG produces a new value of NCYCR each time it is called. When the option data card is omitted NCYCR is entered as RI-2.
7	NEVD	36-40	1-6	Evasion option. The evasion pattern to be followed by the target after counterdetection is designated by this input. See Chapter III, Section A for further discussion. NEVD=1: Target reverses course and reduces speed by one half. NEVD=2: Target alters course clockwise from the true bearing of the attacker, and changes speed. The magnitude of the course change is defined by EVANG, SD-15. The speed change is defined by EVSPD, SD-16.

No.	Name	Field	Limits	Description
	NEVD (cont.)			NEVD=3: Target turns away from the attacker track and steers a course at an angle EVANG, SD-15, relative to the true bearing of the attacker, and changes speed by the amount EVSPD, SD-16. Evasion option 3 is pictured in Figure 2 . NEVD=4: Target turns away from the target track and steers a course at an angle EVANG, SD-15, relative to the reciprocal of attacker course, and changes speed by the amount EVSPD, SD-16. Evasion option 4 is pictured in Figure 3. NEVD=5: No evasion. Counterdetections are suppressed. NEVD=6: Special evasion. Subroutine SPCL is called. SPCL is a dummy routine which may be programmed to meet any special evasion requirements. In its current state, this option will result in the recording of counterdetections at the minimum interval of ETIME, SD-7.
8	NCOMP	46-50	1-5	Intelligence data option switch. This option designates the method of generation of surveillance intelligence estimates. Table I summarizes the values of NCOMP, NOPT (OD-5) and INRAND (OD-9) for each of the permissible intelligence combinations. NCOMP=1: Target estimated position, course and speed are selected randomly from the distribution designated by INRAND, OD-9. The parameters of the position estimate are SPAX, TD-5, and SPAY, TD-6. The parameter for the course estimate is CE, SD-18. The parameter for the speed estimate is SE, SD-17, with the additive factor SAF, SD-19. NCOMP=2: Target estimated position is selected randomly from the distribution designated by INRAND, OD-9,

No.	Name	Field	Limits	Description
	NCOMP (cont.)			NCOMP=2 (cont.): based on the parameters SPAX, TD-5, and SPAY, TD-6. The course and speed estimate is based on two position estimates and the intervening time. Parameters for the initial course and speed estimates are CE, SD-18, and SE SD-17 along with the additive factor SAF, SD-19. Speed estimates are constrained to fall between S-SE and S+SE+SAF, where S is the target leg speed. The computation process is described in Chapter III, Section C under subroutine INTEL, and illustrated in Figure 1.
				NCOMP=3: Target position is derived from input position error information taken from the intelligence data cards. Course and speed are selected randomly as described for NCOMP=1. Estimated target position is on bearing BINP, ID-3, at range RINP, ID-2, from the actual target position at the time of the intelligence detection.
				NCOMP=4: Target position, course and speed estimates are taken from the input information on the intelligence data cards. Determination of the position estimate is as described for NCOMP=3. Course and speed estimates are taken directly from CINP, ID-4, and SINP, ID-5.
				NCOMP=5: Target position estimate is derived from the position error information input on the intelligence data cards. The course and speed estimates are based on two position estimates and the intervening time as described for NCOMP=2. Computation of the position estimate is as described for NCOMP=3.

Note: If NCOMP is assigned the value three, four or five NOPT, OD-5, must be zero.

No.	Name	Field	Limits	Description
9	INRAND	46-50	1-4	Intelligence error distribution switch. Table I summarizes the values of NCOMP (OD-8), NOPT (OD-5) and INRAND for each of the permissible intelligence combinations. If NCOMP is four or five INRAND is ignored. INRAND=1: Intelligence position course and speed errors are selected from a uniform distribution. Maximum position errors are specified by SPAX, TD-5, and SPAY, TD-6, Maximum speed error is SE, SD-17, Maximum course error is CE, SD-18. INRAND=2: Intelligence position error is selected from a normal distribution. Course and speed errors are from a uniform distribution as for INRAND=1. The standard deviations for the X and Y position errors are given by 1/2 SPAX, TD-5, and 1/2 SPAY, TD-6. INRAND=3: Intelligence position error is selected from a uniform distribution as described for INRAND=1. Course and speed errors are selected from a normal distribution with standard deviations of 1/2 CE, SD-18, and 1/2 SE, SD-17, respectively. INRAND=4: Intelligence position error is selected from a normal distribution as for INRAND=2. Course and speed errors are from a normal distribution as for INRAND=3.
10	NC	57-55	0-27, 99	The number of changes to situation inputs from the previous trial. If NC is zero a complete set of situation inputs is required. If NC is 99 the situation data from the previous run will be used, and the situation data and situation change cards must be omitted from the data deck. If NC is assigned a value from one through 27 situation change

No.	Name	Field	Limits	Description
	NC (cont.)			cards specifying NC changes must be included. If the Option card is omitted NC is entered as RI-4.
11	NSUP	56-60	0,1	Run summary supression switch. When activated NSUP reduces the volume of output displayed in the run summary. NSUP=0: The full end of run summary will be printed. NSUP=1: The lists of individual trial results will be deleted from the run summary. Sample means and variances will be retained.
12	NRTT	60-65	0,1	Random target track option. When activated NRTT causes the target to deviate randomly from its assigned track (target track data). NRTT=0: Target track data is used as given. NRTT=1: Target initial position and the course and speed for each leg are selected from uniform distributions. Deviation of initial target X and Y coordinates from the input initial position is limited by SPAX(1), TD-4, and SPAY(1), TD-5. The input initial position is given by XTI, SD-3, and YTI, SD-4. Maximum course and speed deviations are defined by CE, SD-18, and SE, SD-17. The base course and speed for each leg is CST, TD-1, and SPT, TD-2.
13	ICZ	66-70	0,1	Convergence zone intelligence option. This switch is in effect any time CZR, SD-22, is greater than zero. ICZ=0: No convergence zone intelligence will be generated. Detection probability estimates generated within the convergence zone will be used in establishing the trial probability estimate.

No.	Name	Field Limits	Description
	ICZ (cont.)		ICZ=1: Probability estimates generated within the convergence zone are converted to intelligence estimates which are provided immediately to the attacker. If an intelligence estimate is to be generated speed, course range and bearing errors are selected from uniform distributions limited by CZSE, SD-24, CZCE, SD-25, CZRE, SD-26, and CZBE, SD-27, respectively.

Option change cards: When NOC, RI-3, is assigned a value from one through 13 the option data card is replaced by one or more option change cards naming NOC changes to the option data from the previous run. Up to eight changes may be entered on an option change card. Each change is entered as a pair of numbers: the first is the option input number; the second is the revised value. All entries are integer and must be right adjusted within their fields. If NOC is zero, blank or 99 the option change card is omitted.

Field	Description
x1-x5	Option input serial number.
x6-y0	Revised option input value.

(x represents any digit zero through seven. y is x plus one.)

Table I. Intelligence Option Summary.

This table summarizes the input values for the intelligence option switches NOPT, NCOMP and INRAND to achieve each of the possible methods for generating intelligence estimates. The effect of NCOMP values 1 and 2 is independent of the NOPT setting. When NCOMP is assigned 3, 4 or 5, NOPT must be 0.

NOPT	NCOMP	INRAND	Method of estimation
-1			Random intelligence times each trial.
0			Input intelligence times.
1			Random intelligence times first trial.
	1	1	Random uniform position estimate. Random uniform course and speed est.
		2	Random normal position estimate. Random uniform course and speed est.
		3	Random uniform position estimate. Random normal course and speed est.
		4	Random normal position estimate. Random normal course and speed est.
	2	1,3	Random uniform position estimate. Course and speed based on positions.
		2,4	Random normal position estimate. Course and speed based on positions.
0			Input intelligence times.
	3	1,2	Input position estimate. Random uniform course and speed est.
		3,4	Input position estimate. Random normal course and speed est.

Table I. (cont.)

NOPT	NCOMP	INRAND	Method of estimation
0			Input intelligence times.
	4	1-4	Input position estimate. Input course and speed est.
	5	1-4	Input position estimate. Course and speed based on positions.

4. Situation Data Cards

The situation data cards must accompany the first run data set and may be omitted, replaced by situation change cards or included with subsequent data sets. All inputs are decimal and may be placed anywhere within their fields. A decimal point must be included with each entry. The situation input cards must be included whenever NC, RI-4 or OD-10, is zero or blank. The situation data is summarized in Table V.

No.	Name	Card	Field	Units	Limits	Description
1	TEND	1	1-10	hrs	pos	Nominal time to end the trial. No random intelligence times will be generated after TEND. The trial will terminate at TEND + 100 if the normal criteria have not been satisfied. See Chapter III, Section B for details.
2	CINT	1	11-20	hrs	0-TEND	Communication interval. Attacker monitors the intelligence broadcast every CINT hours when not on search station. While on station the attacker monitors the broadcast every two hours. If CINT is zero the attacker will receive intelligence whenever it becomes available (TL, SD-5).
3 4	XTI YTI	1 1	21-30 31-40	mls mls		Initial X and Y coordinates of the target relative to the attacker. XTI is the east-west displacement. YTI is the north-south displacement. Positive entries are north or east. When the random target track option is selected (NRTT, OD-12), (XTI,YTI) represents the

No.	Name	Card	Field	Units	Limits	Description
	YTI (cont.)					center of a rectangle within which the target is randomly located.
5	TL	1	41-50	hrs	pos	Fixed intelligence delay. Surveillance intelligence is held for TL hours before being released for communication to the attacker.
6	TINT	1	51-60	hrs	pos	Intelligence detection interval. Intelligence detections occur at most one time during each successive time period of duration TINT whenever random intelligence times are specified (NOPT, OD-5). The probability of a surveillance detection within the interval is PINT, TD-5. The exact time of detection is placed randomly within the interval.
7	ETIME	1	61-70	hrs	pos	Evasion time. Upon detecting the attacker the target will execute the assigned evasion maneuver (NEVD, OD-7) for an interval of length ETIME. Counterdetections are suppressed during the evasion interval.
8	SS	2	1-10	kts	pos	Search speed. The attacker uses this speed while on station for improved sonar performance.
9	SA	2	11-20	kts	pos	Transit speed. The attacker uses this speed to proceed to search station in response to intelligence data.
10	VI	2	21-30	kts	pos	Initial speed of attacker used prior to receipt of the first intelligence data.
11	CAI	2	31-40	deg	0-360	Initial course of attacker used prior to receipt of the first intelligence data.

No.	Name	Card	Field	Units	Limits	Description
12	SI	2	41-50	hrs	pos	Search leg time. Upon arrival on station the attacker searches on a course perpendicular to the estimated target course for 1/2 SI, then reverses course every SI hours thereafter until new intelligence is received.
13	AMB	2	51-60	db		Ambient noise level. AMB is a term of the sonar equation representing a lower bound on self noise regardless of the values derived from the self noise curves.
14	SIGMA	2	61-70	db	pos	Standard deviation of propagation loss. SIGMA is used with the sonar equation to estimate detection probabilities.
15	EVANG	3	1-10	deg	0-360	Target evasion angle. In executing evasion patterns 2, 3 or 4 target evasion course is determined by the geometry at counterdetection and EVANG. (NEVD, OD-7)
16	EVSPD	3	11-20	kts	note	Evasion speed increment. In executing evasion patterns 2, 3 or 4 target evasion speed is leg speed plus EVSPD. (NEVD, OD-7)

Note: EVSPD may be positive or negative, but if negative it must not be permitted to drive the target speed to zero or below during evasion. Target leg speed, SPT, TD-2, random track option NRTT, OD-12, and speed error, SE, SD-17, must be considered.

No.	Name	Card	Field	Units	Limits	Description
17	SE	3	21-30	kts	note	Speed error. Intelligence speed estimation by the surveillance facility uses SE as the maximum error of a uniform distribution or two standard deviations of a normal distribution. In the latter case SE defines

No.	Name	Card	Field	Units	Limits	Description
	SE (cont.)					a region in which 98.85% of the errors are expected. When the intelligence speed estimate is computed from position estimates SE is the maximum positive speed error, and is combined with SAF, SD-19, to form a limit on negative error. SE is the maximum deviation from assigned target track speed SPT, TD-2, under the random target track option, NRTT, OD-12.

Note: Under the fixed target track option SE must be positive and less than the minimum target leg speed. Under the random target track option SE must be less than one half the minimum target leg speed. This will assure that target speed and estimated speed will not be driven to zero or below.

No.	Name	Card	Field	Units	Limits	Description
18	CE	3	31-40	deg	0-360	Course error. Intelligence course estimation by the surveillance facility uses CE as the maximum error of a uniform distribution or two standard deviations of a normal distribution. In the latter case CE defines a region in which 98.85% of the errors are expected. CE is the maximum deviation from the assigned target track course, CST, TD-3, under the random target track option, NRTT, OD-12.
19	SAF	3	41-50	kts	pos	Safety factor. When the surveillance intelligence speed estimate is generated by VIM, and for all CZ intelligence estimates, SAF is added to the estimated speed in an attempt to force the attacker to a search station ahead of the actual target. When intelligence speed is based on position estimates SAF is combined with SE, SD-17, to

No.	Name	Card	Field	Units	Limits	Description
	SAF (cont.)					establish a limit on negative speed error.
20	GAINA	3	51-60	db		Attacker sonar gain. GAINA is used in the sonar equation for estimating detection probability, and is composed of recognition differential, Nrd, and directivity index, Ndi, associated with the attacker's sonar suite)(GAINA=Nrd-Ndi)
21	GAINT	3	61-70	db		Target sonar gain. GAINT is used in the sonar equation for determining counterdetection range, and is composed of recognition differential, Nrd, and directivity index, Ndi, associated with the target's sonar suite. (GAINT=Nrd-Ndi)
22	CZR	4	1-10	mls	non-neg	Convergence zone central radius. CZ events occur when the range between the ships is as near the central CZ radius as possible based on the current relative track. If no convergence zone is represented on EC-5, CZR should be set to zero. The nature of the CZ event is designated by ICZ, OD-13.
23	CZW	4	11-20	mls	0-CZR	Convergence zone half width. The outer CZ radius is given by CZW + CZR (SD-22). The inner CZ radius is CZR-CZW. During the time the range between the units falls within the minimum and maximum CZ radii exactly one CZ event will occur.
24	CZSE	4	21-30	kts	note	Convergence zone speed error. When a convergence zone intelligence estimate is generated, the speed error is selected randomly

No.	Name	Card	Field	Units	Limits	Description
	CZSE (cont.)					from a uniform distribution with CZSE representing the maximum error. (ICZ, OD-13)

Note: To prevent a negative speed estimate, CZSE should be less than the minimum target leg speed. If the random target track option (NRTT, OD-12) is activated the minimum target leg speed should be greater than CZSE+SE, SD-17.

No.	Name	Card	Field	Units	Limits	Description
25	CZCE	4	31-40	deg	0-360	Convergence zone course error. When a convergence zone intelligence estimate is generated, the course error is selected randomly from a uniform distribution with CZCE representing the maximum error. (ICZ, OD-13)
26	CZBE	4	41-50	deg	0-360	Convergence zone bearing error. When a convergence zone intelligence estimate is generated, the position error is computed from a bearing and range error (CZRE, SD-27). The bearing error is selected randomly from a uniform distribution with CZBE representing the maximum error. (ICZ, OD-13)
27	CZRE	4	51-60	mls		Convergence zone range error. When a convergence zone intelligence estimate is generated, the position error is computed from a range and bearing error (CZBE, SD-26). The range error is selected randomly from a uniform distribution with CZRE representing the maximum error. (ICZ, OD-13)

Situation change cards: When NC, RI-4 or OD-10, is assigned a value from one through 27 the situation data cards are replaced by one or more situation change cards naming NC changes to the situation data from the previous run. Up to five changes may be entered on each change card. Each change is represented by a pair of numbers: the first is the integer valued situation input number; the second is the revised (decimal) value which may appear anywhere in its assigned field and must include a decimal point. If NC is zero, blank or 99 the situation change cards must be omitted.

Fields	Description
1- 5 16-20 31-35 46-50 61-65	Situation input serial numbers.
6-15 21-30 36-45 51-60 66-75	Revised situation input values.

5. <u>Target Track Cards</u>

Course, speed and surveillance system detection parameters for each leg are the components of the target track data. One card is required for each leg of the target's transit path, with the number of legs specified by M, OD-2. If M is zero the target track cards must be omitted and the target track from the previous run will be used. Target track cards must be included with the first run data set. All entries are decimal and may be located anywhere within their fields. Decimal points must be included. The target track data is summarized in Table VI.

No.	Name	Field	Units	Limits	Description
1	CST(I)	1-10	deg	0-360	Base course for leg I. Prior to the leg termination time, TT, TD-3, the target will deviate from this course only in response to a counterdetection (NEVD, OD-7) or in response to the random track option, NRTT, OD-12.
2	SPT(I)	11-20	kts	pos	Base speed for leg I. Prior to the leg termination time, TT, TD-3, the target will deviate from this speed only in response to a counterdetection (NEVD, OD-7) or in response to the random track option, NRTT, OD-12.
3	TT(I)	21-30	hrs	pos	Terminal time for leg I. When problem time equals terminal time for the leg, the target track index is incremented and the parameters for the next track leg are activated. The terminal time for the final leg must exceed TEND, SD-1, by more than 100 hours.
4	PINT(I)	31-40		0-1	Intelligence detection probability. Under the random intelligence time option, NOPT, OD-5, the surveillance facility will detect the target on leg I with probability PINT during each successive interval of length TINT, SD-6.
5 6	SPAX(I) SPAY(I)	41-50 51-60	mls mls		Surveillance position error parameters. When a random position estimate is generated by VIM, SPAX and SPAY are the maximum X and Y deviation of a uniform error, or two standard deviations of a normally distributed error. In the latter case, SPAX and SPAY define regions of the X and Y axes in which 98.85% of the error is expected. (NCOMP, OD-8; INRAND, OD-9) When the random track option is

No.	Name	Field	Units	Limits	Description
	SPAX, SPAY (cont.)				activated (NRTT, OD-12) SPAX(1) and SPAY(1) represent the maximum deviations from XTI, SD-3, and YTI, SD-4.

6. Intelligence Data Cards

The intelligence data cards refer to surveillance system detections and consist of detection time and related course, speed and position estimates. One card is required for each intelligence detection. The number of detections is specified by N, OD-3, which should be zero whenever NOPT, OD-5, is not zero. If both N and NOPT are zero, the intelligence data cards must be omitted and the intelligence data input for the previous run will be used. If N is zero and NOPT is not zero the intelligence data cards must be omitted and random intelligence data will be generated within VIM. All entries are decimal and may be located anywhere within their fields. Decimal points must be included. The intelligence data is summarized in Table VII.

No.	Name	Field	Units	Limits	Description
1	TI(J)	1-10	hrs	pos	The time of intelligence detection J. When problem time equals intelligence detection time, the course speed and position will be estimated in accordance with the intelligence option switches NCOMP, OD-8, and INRAND, OD-9.
2	RINP(J)	11-20	mls	pos	Range error for intelligence detection J. If NCOMP, OD-8, is one or two this entry may be blank. Otherwise, intelligence position is based on range error and bearing from

No.	Name	Field	Units	Limits	Description
	RINP (cont.)				actual target position (BINP, ID-2).
3	BINP(J)	21-30	deg	0-360	Bearing from target of intelligence position estimate J. If NCOMP, OD-8, is one or two this entry may be blank. Otherwise, intelligence position is based on the bearing from the target and the input range error BINP, ID-2.
4	CINP(J)	31-40	deg	0-360	Course estimate for intelligence detection J. This entry is required only when NCOMP, OD-8, is assigned the value four.
5	SINP(J)	41-50	kts	pos	Speed estimate for intelligence detection J. This entry is required only when NCOMP, OD-8 is assigned the value four.

7. Terminal Card (99999 Card)

Following the last data card from the data set for the final run, the terminal card signals the end of the data set. This card is described in Table VIII.

Field	Description
1-5	99999

Table II. Environmental Data Summary

Title card:

Field	Description
2-80	Users message.

Attacker noise curves: Decimal entries.

Name	Field	Units	Description
VN(I)	10 col	kts	Attacker speed card. I=1,...,7.
SNA(I)	10 col	db	Attacker self noise. I=1,...,7.
RNA(I)	10 col	db	Attacker radiated noise. I=1,..,7.

Target noise curves: Decimal entries.

Name	Field	Units	Description
STN(I)	10 col	kts	Target speed card. I=1,...,7.
SNT(I)	10 col	db	Target self noise. I=1,...,7.
RNT(I)	10 col	db	Target radiated noise. I=1,...,7.

Propagation loss curve: Decimal entries.

Name	Field	Units	Description
PLOS(I)	10 col	db	Propagation loss. I=1,...,7.
RDET(I)	10 col	mls	Range of loss. I=1,...,7.

Table III. Run Identification Summary

Run number card: Integer entries.

No.	Name	Field	Description
1	NUMBER	1- 5	Run identification number.
2	NCYCR	6-10	Random number seed (OD-6).
3	NOC	11-15	Number of option changes.
4	NC	16-20	Number of situation changes. (OD-10).

Run description card: User's message in columns two through 80.

Table IV. Option Data Summary: Integer Entries.

No.	Name	Field	Limits	Description
1	NTRIAL	1-100	1-100	Number of trials.
2	M	6-10	0- 50	Number of target tracks cards.
3	N	11-15	0-100	Number of intelligence detection cards.
4	IOPT	16-20	1- 5	Output option. IOPT=1: Details each trial; trial sum. 2: Details first trial; trial sum. 3: Trial summaries. 4: Details first trial. 5: No trial details.
5	NOPT	21-25	-1,0,1,	Intelligence time option. NOPT=-1: Random times each trial. 0: Input times. 1: Random times first trial for all trials.
6	NCYCR	26-35	1-10^{10}	Random number seed. (RI-2)
				Evasion option. NEVD=1: Course reversal. 2: Course change relative to attacker bearing. 3: Course change away from attacker bearing. 4: Course change away from attacker course. 5: No evasion. 6: User's choise (SPCL).
				Intelligence data option. NCOMP=1: Random position, course and speed. 2: Random position, computed course and speed. 3: Input position, random course and speed.

No.	Name	Field	Limits	Description
	NCOMP (cont.)			4: Input position, course and speed. 5: Input position, computed course and speed.
9	INRAND	46-50	1-4	Intelligence error distribution switch. INRAND=1: Uniform position, course and speed. 2: Normal position, uniform course and speed. 3: Uniform position, normal course and speed. 4: Normal position, normal course and speed.
10	NC	51-55	0-27, 99	Number of situation data changes. (RI-4)
11	NSUP	56-60	0,1	Run summary supression switch. NSUP 1: Individual trial statistics omitted from run summary.
12	NRTT	61-65	0,1	Random target track option switch. NRTT 1: This option is activated.
13	ICZ	66-70	0,1	Convergence zone intelligence option. ICZ 0: Detection probabilities included overall estimate. 1: Detection probabilities converted to CZ intelligence.

Option change card: Integer entries

Field	Description
x1-x5	Option input number.
x6-y0	Option input value.

(x represents any digit zero through seven. y is x plus one.)

Table V. Situation Data Summary: Decimal Entries.

No.	Name	Card	Field	Units	Limits	Description
1	TEND	1	1-10	hrs	pos	Nominal time to end trial.
2	CINT	1	11-20	hrs	0-TEND	Communications interval. CINT 0: Intelligence transmitted when ready.
3	XTI	1	21-30	mls		Initial target coordinates.
4	YTI	1	31-40	mls		
5	TL	1	41-50	hrs	pos	Intelligence delay time.
6	TINT	1	51-60	hrs	pos	Intelligence detection interval.
7	ETIME	1	61-70	hrs	pos	Evasion time.
8	SS	2	1-10	kts	pos	Attacker search speed.
9	SA	2	11-20	kts	pos	Attacker transit speed.
10	VI	2	21-30	kts	pos	Initial attacker speed.
11	CAI	2	31-40	deg	0-360	Initial attacker course.
12	SI	2	41-50	hrs	pos	Attacker search leg time.
13	AMB	2	51-60	db		Ambient noise level.
14	SIGMA	2	61-70	db	pos	Standard deviation of propagation loss.
15	EVANG	3	1-10	deg	0-360	Target evasion angle.
16	EVSPD	3	11-20	kts	note[1]	Target evasion speed.
17	SE	3	21-30	kts	note[1]	Intelligence speed error.
18	CE	3	31-40	deg	0-360	Intelligence course error.

---

[1] These entries must be chosen so that target track speeds or intelligence speed estimates cannot take on negative values.

No.	Name	Card	Field	Units	Limits	Description
19	SAF	3	41-50	kts	pos	Intelligence speed safety factor.
20	BAINA	3	51-60	db		Attacker sonar gain.
21	GAINT	3	61-70	db		Target sonar gain.
22	CZR	4	1-10	mls	non-neg	CZ central radius.
23	CZW	4	11-20	mls	0-CZR	CZ half width.
24	CZSE	4	21-30	kts	note[2]	CZ speed error.
25	CZCE	4	31-40	deg	0-360	CZ course error.
26	CZBE	4	41-50	deg	0-360	CZ bearing error.
27	CZRE	4	51-60	mls		CZ range error.

Situation change cards:

Fields	Description	Fields	Description
1- 5 16-20 31-35 46-50 61-65	Input numbers.	6-15 21-30 36-45 51-60 66-75	Input values.

[2]Ibid.

Table VI. Target Track Summary: Decimal Entries.

No.	Name	Field	Units	Limits	Description
1	CST(I)	1-10	deg	0-360	Base target course, leg I.
2	PT(I)	11-20	kts	pos	Base target speed, leg I.
3	TT(I)	21-30	hrs	pos	Terminal time, leg I.
4	PINT(I)	31-40		0-1	Intelligence detection probability, leg I.
5	SPAX(I)	41-50	mls		Surveillance position error parameters, leg I.
6	SPAY(I)	51-60	mls		

Table VII. Intelligence Data Summary: Decimal Entries.

No.	Name	Field	Units	Limits	Description
1	TI(J)	1-10	hrs	pos	The time of intelligence detection J.
2	RINP(J)	11-20	mls		Intelligence range error, detection J.
3	BINP(J)	21-30	deg	0-360	Intelligence position bearing from target, detection J.
4	CINP(J)	31-40	deg	0-360	Intelligence course estimate, detection J.
5	SINP(J)	41-50	kts	pos	Intelligence speed estimate, detection J.

Table VIII. Terminal Card: Integer Entry.

Field	Description
1-5	99999

B. DATA DECK ASSEMBLY

The data deck is composed of a set of environmental cards, first run data and the input cards for subsequent runs. The environmental set as described in Chapter V, Section A-1 is placed in front of the deck. The first run data includes the run identification cards, the option data card, the situation data cards and the target track data. If intelligence times are to be input, intelligence data cards must also be included. The minimum input for subsequent runs is comprised of the run identification cards. In addition, there may be an option card or change cards, situation cards or change cards, a revised target track, and revised intelligence data. Table IX is an outline of a typical data set assembly. Figure 19 shows the complete data deck assembly. Figure 20 is the example data deck used to generate Figures 13 through 16.

Job control cards: The exact job control cards are a function of the system being used. The job control cards required by the IBM system 360 installation at the Naval Postgraduate School are listed in Table X. Part A of Table X shows the cards required to compile and execute the VIM FORTRAN source and data. VIM is currently held in disc storage at the NPS computer facility. Part B of Table X lists the cards required for use of the stored program.

Table IX. Data Set Assembly

Environmental data
- Title card
- Attacker noise curves
- Target noise curves
- Propagation loss curve

First run data
- Run identification cards
- Option data card
- Situation data cards
- Target track cards
- Intelligence data cards (optional)

Subsequent runs
- Run identification cards
- Option data card (optional)
- Option change card (optional)
- Situation data cards (optional)
- Situation change cards (optional)
- Target track cards (optional)
- Intelligence data cards (optional)

Terminal card

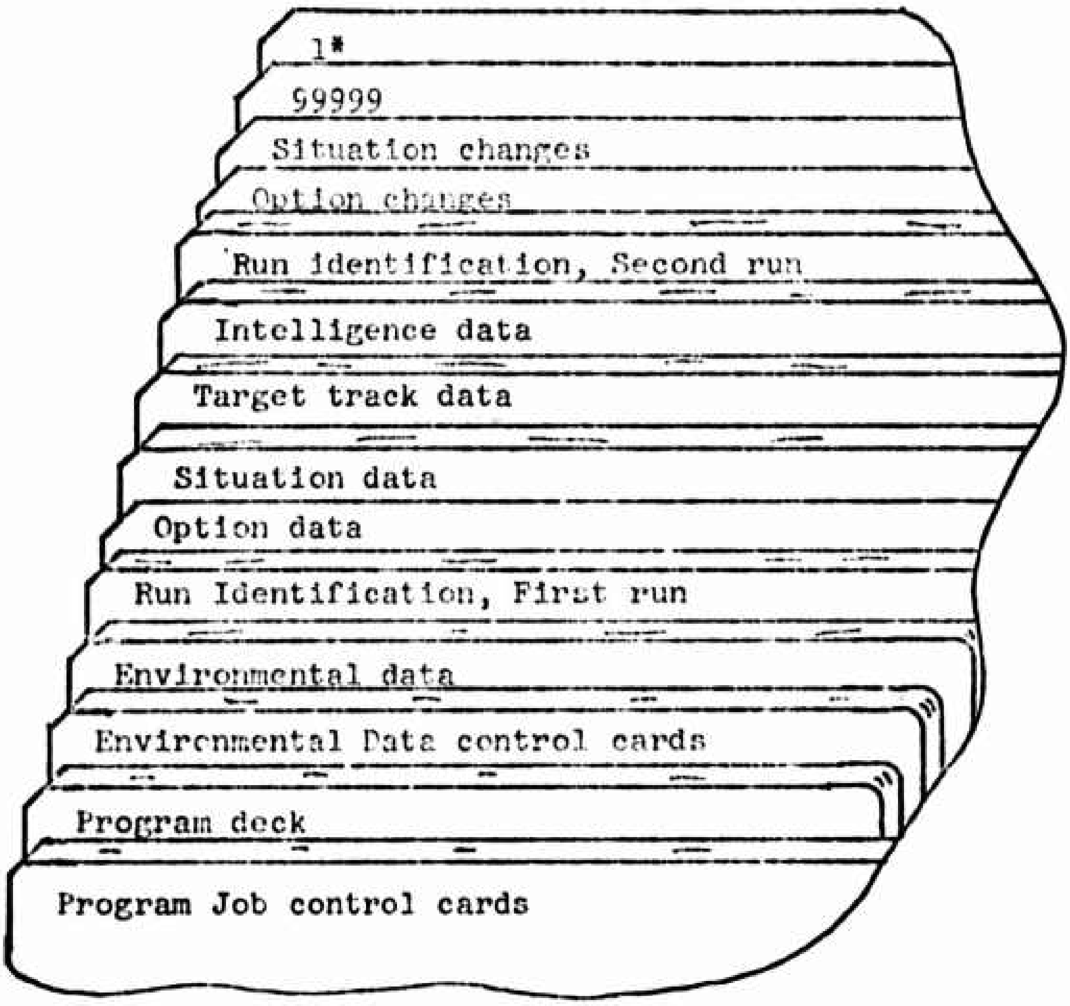


Figure 19. Data Deck Assembly for a Series of Two Runs

FIGURE 20 SAMPLE DATA DECK FOR THREE RUNS

```
SAMPLE DATA SET WITH CONVERGENCE ZONE ( PREPARED FOR VIM USERS MANUAL )

     0.       3.      10.      15.      22.      25.      32.  ATTACK SPD
   -45.     -40.     -30.     -22.     -12.      -7.       0.    SELF NSE
     3.       9.      17.      24.      34.      36.      42.    RAD NSE

     0.       5.      10.      15.      20.      25.      30.  TARGET SPD
   -33.     -28.     -22.     -17.     -11.      -6.       0.    SELF NSE
    12.      12.      13.      17.      23.      32.      42.    RAD NSE

    75.      92.     100.      85.      90.     115.     127.  PROP LOSS
     5.      17.      30.      35.      45.      50.     100.    RANGE

101                                                             RUN ID CRD
FIRST SAMPLE RUN- RAND TARG TRK, TRIAL HIST, TRIAL SUM, INPUT INTEL, CZ INTEL
 10    2    3    2    0 148597321    4    4    1    0    0    1    1  OPT CRD
    48.       2.       0.     500.      1.2       4.      2.5  SIT CARD 1
    13.      20.       .1       0.      2.5     -42.       9.  SIT CARD 2
    60.      -3.       3.      30.      3.5      36.      34.  SIT CARD 3
    40.       7.       4.      15.      2.5       5.           SIT CARD 4

   180.      16.      0.1       .0     500.       0.           TRGT TRK 1
   180.      16.     200.      25.      25.      25.           TRGT TRK 2

     1.      13.      25.     168.      13.                    INT DATA 1
    15.      22.      84.     205.      18.                    INT DATA 2
    30.       9.     156.     168.      15.                    INT DATA 3

102 758218413   6   1                                          RUN ID CRD
2ND SAMPLE RUN - RAND TRACK,NO HIST,SUP SUM,INPUT INTEL.NO CZ INTEL,CONST COMM
 2    0    3    0    4    5   11    1    1  100   13    0      OD CHG CRD
 2         0.                                                  SD CHG CRD

103      956    3   1                                          RUN ID CRD
3RD SAMPLE RUN - FIXED TRACK, NO HIST, SUP SUM, RAND INTEL,NO CZ
 5   -1    8    1    9    1                                    OD CHG CRD
22       0.                                                    SD CHG CRD
99999                                                          FINAL CARD
```

Table X. Job Control Cards

A. Compile and execute

```
//        Job card
//        EXEC    FORTCLG, REGION.GO=110K
//FORT.SYSIN    DD    *
          SOURCE DECK
/*
//GO.FT06F001   DD    SYSOUT=A,SPACE=(CYL,(1,1))
//GO.SYSIN      DD    *
          DATA DECK
/*
```

B. Disc storage

```
//        Job card
//JOBLIB        DD    DSNAME=S0802,KILSUB,DISP=SHR,
//                    VOLUME=SER=MARY,UNIT=2314
//STEP1               EXEC    PGM=VIM,REGION=110K
//FT06F001      DD    SYSOUT=A,STACE=(CYL,(1,1))
//FT05001       DD    *
          DATA DECK
/*
```

VI. VIM EXPERIMENTATION

The purpose of this chapter is to describe the use of VIM in general terms. Section A provides a discussion of problem formulation and the relation to the problem in qualitative terms of the input parameters. Section B is an illustration of the use of VIM as applied to a typical problem.

A. FORMULATION OF THE EXPERIMENT

Formulating a simulation experiment involves defining an objective, developing a scenario compatible with the model, enumerating the output data desired and assigning values to the input parameters compatible with the objective, the scenario and the desired output.

Objective: The goals of the experiment must be clearly defined in terms of the problem faced and the measure of effectiveness to be used. For example, the measure of effectiveness might be cumulative detection probability or number of counterdetections.

Scenario: The scenario must relate the problem to the model. The key elements of the VIM scenario are the transmitting target, a waiting attack submarine, a remote intelligence facility, the sonar environment, reaction of the target to counterdetections, and the fact that the response of the attacker to a detection opportunity is to record the probability of detection and continue its search plan. Since the geometry of VIM is similar to that encountered in a variety of situations, the elements of the problem must be carefully identified with the elements of the model. Frequently assumptions must be made regarding the problem to satisfy the requirements of the model. Each of these assumptions must be carefully justified in light of the potential effect on the outcome.

Output data: Certain data is compiled by VIM automatically, such as overall detection probability, maximum detection probability, counterdetection data, times associated with maximum probability of detection and times associated with convergence zone events. Easily obtained from the trial summaries is the distribution of detection probabilities over time for each trial. Other data is available from the detailed trial history.

Input parameters: The variables controlled by input were selected to provide a maximum freedom in fitting a scenario to VIM. All may have a significant effect on the outcome and the values entered should be the result of careful research as well as a clear understanding of the input description.

The environmental data should reflect the best available knowledge of the sound propagation profile of the area under consideration and the noise characteristics of the submarines being studied. Because of the imprecise nature of the ocean environment and the variation between ships of the same class, a parametric analysis of this data group may be in order.

Target leg changes in VIM are intended to interact with the intelligence facility as distinguished from interaction with the attacker. Changes which would not be discernable to the assumed intelligence platform should not be included. Particularly in the case of intelligence course and speed computed from position estimates, frequent leg changes with only minor modifications will result in unrealistically poor intelligence estimates. In general, target track should be as simple and direct as the nature of the study permits. If random tracks are used it should be only after it has been determined that the increased variation is necessary to adequately reflect the system being modeled.

Random intelligence times may be required to simulate the rate at which a surveillance facility generates intelligence estimates on transiting targets. The parameters of the random intelligence time option are a time interval TINT, SD-13, and the probability PINT, TD-4, that a surveillance facility will generate an estimate during the interval. The intelligence rate is matched by the ratio of PINT:TINT, where PINT is between zero and one. If TINT is very small a poisson process is approximated. As TINT is increased a limit on the maximum frequency of intelligence estimates is established with the time between the estimates taking on a more regular pattern. For example, assume that it takes a submarine six hours to transit an intelligence window, with an average of 3/4 estimates each transit and a maximum of 2 estimates on any transit. The pairs (3/4,6), (3/8,3) and (3/24,1), where the first number represents PINT and the second TINT, would all satisfy the requirement of 3/4 estimates per transit. Only the second pair would satisfy the limitation that at most 2 estimates could occur on any transit.

Input intelligence times taken from empirical observations can be used to validate the model and assist in adjusting inputs so that exercise results may be extrapolated to a more general situation with a degree of confidence. If the problem permits this, it is highly desirable.

The nature of the convergence zone inputs is dictated by the problem. If convergence zone intelligence is to be generated the error parameters should reflect the errors which would be expected in the submarine versus submarine tracking problem at convergence zone ranges.

The number of trials per run is a fuction of the desired level of statistical significance. If the parameter to be measured is one of the statistics included in the run summary, the average over the runs and the sample variance will be listed. If the number of trials, N, is large it may be assumed that the average value is a normal random variable with variance equal to V/N, where V is the listed sample variation. Let c be the level of confidence with which the results from two runs are to be declared to be from different distributions; i.e., that the two averages represent a different result based on the input parameters as distinguished from a random difference. Let Z(c) represent the number of standard deviations from the mean of a standard normal distribution within which the expected fraction of realizations is c. The minimum separation between observed averages which may be declared different is

$$d = + Z(c)\sqrt{2V/N}$$

and if d is specified, the required number of trials is

$$N = 2VZ^2(c)/d^2$$

Verification: Before generating the experimental data, it is desirable to verify that the program is responding properly to the input data. The trial history is an excellent tool for this task. A sample trial can be plotted based on the information provided with each event and the plot examined for signs of program and data errors or misinterpretations.

Validation: Whenever possible the results of the simulation should be checked with empirical data to determine if essential differences exist which might require reformulation of the problem or if there is sufficient agreement to justify confidence in the results where no empirical data exists. As pointed out above, the various forms of intelligence input and computation are particularly well suited to this task.

B. VIM EXAMPLE

This typical problem formulation was developed to assist the user in becoming familiar with VIM. Initially the problem is outlined and the scenario is defined. The control parameters are isolated and input data requirements are outlined. Finally, the experimental plan is described and the results presented.

Problem: An attack submarine has been assigned the task of intercepting at close range a transiting target submarine. The commander of the attack submarine desires to use tactics which will maximize his detection probability. The decision variables under the control of the attack submarine are listed in Table XI.

Table XI. Example Problem Control Variables

A list of the variables under the control of the attack submarine commander, along with their program names, input reference numbers and ranges of permissible values.

Variable	Name, Ref.	Range
Attacker transit speed	SA, SD-9	15-25 knots
Attacker search speed	SS, SD-8	8-16 knots
Communications interval	CINT, SD-2	2,4,...,12 hours
Distance of attacker from northern boundary of corridor	YTI, SD-4	0-2000 miles
Duration of attacker learch leg	SI, SD-12	0-12 hours
Speed estimate safety factor	SAF, SD-19	0-8 knots

Scenario: A potential enemy must use an ocean lane 400 miles wide and 800 miles long for its submarines to transit from home port to their operating stations. During a transit of the lane a shore based intelligence facility maintains intermittent contact with the transitting submarine and makes periodic position, course and speed estimates. Upon leaving the transit lane the target may head for any one of several operating areas. The surveillance system is unable to estimate the new course. It is desired that an attack submarine be sent to the area to establish sonar contact with a transitting target submarine. The political climate is such that if the attack submarine is counterdetected the target will neither evade nor use weapons.

Data requirements: The key data in this problem include the environmental data, target track data, communications delay, the intelligence parameters and number of trials per run. The environmental data (including the related situation data inputs) is typical of the ships and ocean area being considered. No convergence zone is present.

The target track started at a point north of the attacker and two hundred miles to the east and headed due south at sixteen knots, the assumed transit speed of the target. After 800 miles on the southerly heading, the target turned east at the same speed. By this means the 400 mile wide corrider was depicted with the attacker on the centerline of the lane and the target proceeding along the boundary. This represented the worst case from the point of view of the attacker. The 90 degree turn after 800 miles represented a turn to an unknown destination. Surveillance detection probability was set to zero on this leg.

The communications delay was that expected for the surveillance system.

Observations from the area of interest indicate that the intelligence facility expects four intelligence estimates during the course of a target transit with no more than three in any 12 hour period. This was approximated by setting the probability of a surveillance detection during a four hour period to one third. It was further assumed that the position estimate provided by the attacker would fall uniformly within a 40 mile square centered at the actual target position, with course and speed estimates based on successive position estimates and speed error limited to three knots.

The number of trials for each run was selected to distinguish between average probability estimates differing by .03 with 70% confidnnce. A test run of 25 trials was made which indicated the variance for detection probability was .16. The number of trials required per run was

$$N = 2\ Z^2(.7)V/d^2 = 2x(1.05)^2x0.16/(0.03)^2 = 400.$$

Since VIM is capable of only one hundred trials per run it was necessary to conduct each run four times.

Experimental plan: A six variable search plan was developed to find the combination of variables over the permissible range which would produce the maximum detection probability. It was assumed that the probability of detection is a smooth function of the six parameters and that a single relative maximum exists over the range of the study. The variables were searched one at a time for a maximum resultant detection probability according to the following plan:

1. A base value and step value were arbitrarily assigned to each variable.
2. A run (400 trials) was made with each variable at its base value.
3. A run with five variables assigned base values and one altered by its step value was conducted for each of the variables.
4. The variable which demonstrated the greatest effect on detection probability was identified. A simultaneous search of up to eight values of the variable was conducted to estimate the value which maximized detection probability. The maximizing value became the base for this variable.
5. Using the revised base steps three and four were repeated until no further improvement was indicated.

Experimental Results: In the discussion that follows, the data from each series of runs is summarized in tables, analyzed in view of determining maximum detection probability and the following series specified. A series refers to a set of several runs which are expected to provide the answer to the problem of which variables may be adjusted to improve detection probability, or what value of a variable provides the maximum detection probability for given values of the other variables.

Series I was a search from the base case for the variable which might produce the greatest improvement. Series I results are shown in Table XII which lists the base value for each variable, the increment by which each was varied, the average probability achieved for each variable at its incremented value, and the difference of the incremented results from the base result. Because of the large number of trials for each run (400), the average probability may be assumed to be a normally distributed random variable with variance V = .16/400 = .0004. The variance of the difference of two such random variables is .0008 with standard deviation of .0283. The probability that two of the random variables with the same mean would differ by .03 is less than .3, and the probability of a difference of .06 is less than .001. With better than 99% confidence, then, it can be inferred that the expected detection probability with transit speed set at 22 knots is greater than the expected result with transit speed of 20 knots. Series II was a search of values of transit speed to estimate the maximizing value.

In Table XIII is listed the results of varying attacker transit speed in one knot increments from 20 to 25 knots.

Table XII. Series I Results

Variable	CINT	YTI	SS	SA	SI	SAF	Base Case
Base Value	4	400	13	20	2.31	4	
Increment	-2	-50	+2	+2	+.23	-.5	
Probability	.4575	.4425	.470	.5375	.4750	.4750	.470
Difference	-.0125	-.0275	0	+.0675	-.0325	+.005	

Table XIII. Series II Results

Search of attacker transit speed.

SA	20*	21	22*	23	24	25
Probability	.470	.460	.5375	.4825	.5250	.5850

* Series I results.

Figure 21 is a plot of the results with a least squares regression line indicating the trend. Since the results seem to be increasing with transit speed and transit speed is constrained less than 25 knots, the maximizing value is taken to be 25 knots which is used as the new base value. Series III was a check of all variables one at a time using the revised base.

Table XIV lists the revised base values and increment values for each variable along with the resultant probabilities and differences. In this case communications interval, CINT, showed the greatest deviation, while search speed, SS, initial position, YTI, and estimation safety factor, SAF, all showed significant deviation.

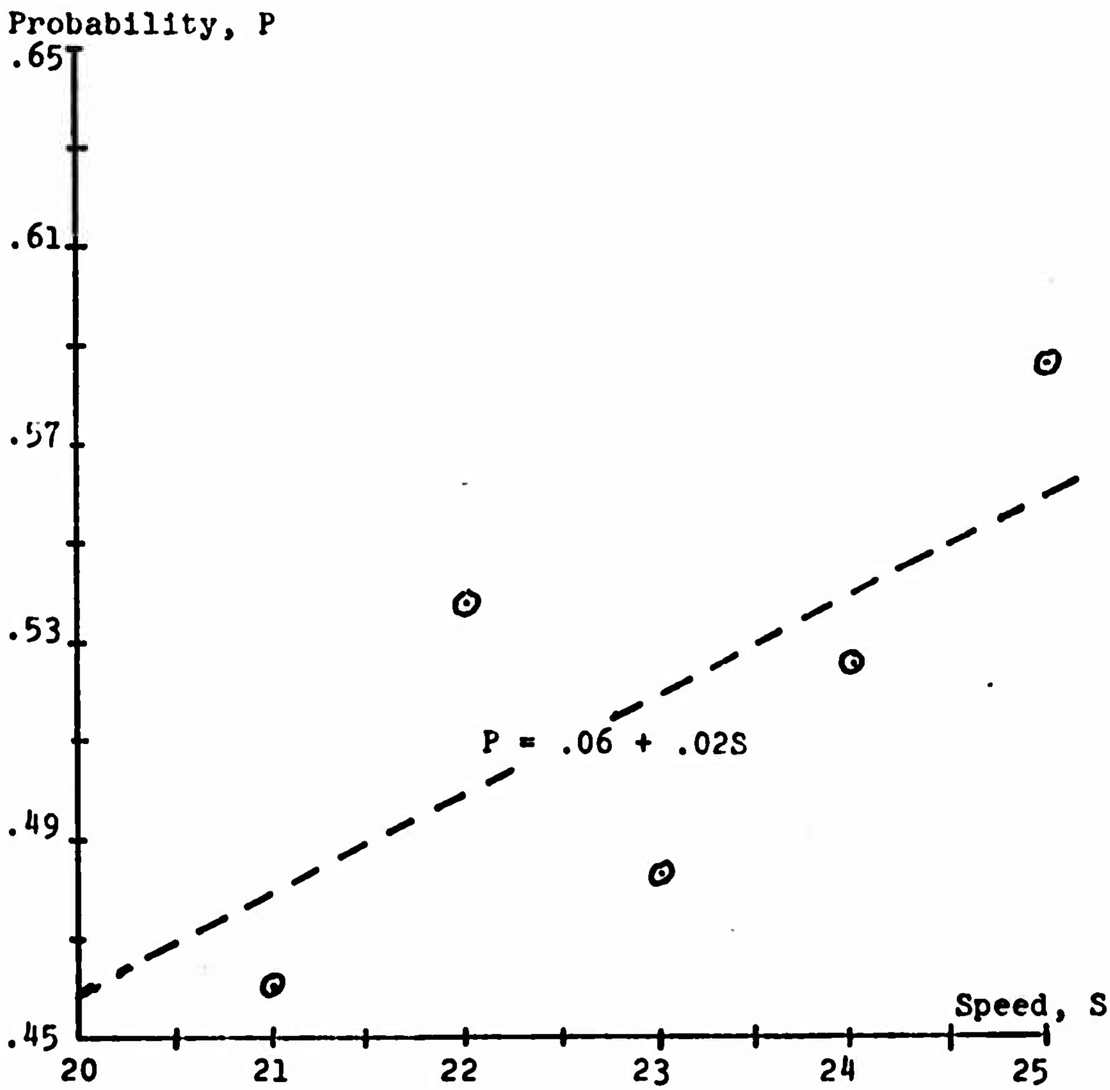


Figure 21. Series II Data with Least Squares Regression Line.

Table XIV. Series III Results

Variable	CINT	YTI	SS	SI	SAF	ALL
Base Value	4	400	13	2.31	4	BASE
Increment	+4	+100	-3	+.23	-1.5	VALUES
Probability	.4575	.5425	.4850	.5650	.5375	.5875*
Difference	-.1275	-.0425	-.10	-.02	-.0475	

* Series II results.

Series IV was a search of the permissible communications intervals, CINT, for the maximizing value. Table XV shows the results of this search. The values achieved with CINT equal to 6 or 8 are obviously lower than those for CINT equal to 2 or 4, but there is insufficient information to distinguish between 2 and 4 hour communications intervals, and the base value was left at 4 hours.

Series V commenced a search of attacker search speed and interval. The base interval represents a search leg of 30 miles at 13 knots. It is reasonable to suppose that a coordinated adjustment of search interval and search speed

Table XV. Series IV Results

Search of communications interval

CINT	8	6	4	2
Probability	45.75*	50.75	56.37@	57.0

* Series III results.

@ Average of Series II and Series IV results.

might have greater effect on detection probability than either variable leg itself. Series V examines search speed alone. Series VI examines search interval alone. Series VII and VIII look at the joint variation of search speed and search interval. Table XVI lists the results of the search speed experiments. Although there is a peak at 13

Table XVI. Series V Results

Search over values of search speed

SS	10	12	13	14	16	18	20
Probability	51.25	53	56.37*	54	52	46.25	46.5

* Average of Series II and Series IV results.

knots, there is little statistical difference over the range 12 to 14 knots. Thirteen knots was retained as the value of search speed.

Table XVII lists the results of the search interval experiment with search speed fixed at 13 knots. Figure 22 is a plot of the results. The table and figure indicate a degree of stability over the range of 1/2 to 3 hours. The average result from all runs for which SI is no greater than 3 hours is shown in Figure 23. There is no reason to reject the hypothesis that all results within this band were from the same distribution with the mean equal to the sample average. When the average is taken over all runs for which the value of SI is no greater than 5, neither the

Table XVII. Series VI Results

Search over values of Search Interval.

SI	.5	1.	1.5	1.75	2.0	2.25
Probability	54.75	55.5	51.25	56.75	54.25	53.25

SI	2.31	2.5	2.54	2.75	3.0	3.5
Probability	56.37*	51.5	56.5	51.75	53.5	49

SI	4	5	8
Probability	48.5	49.5	43.0

* Average of Series II and IV results.

three largest nor the three smallest values within the band could reasonably be assumed to come from a normal distribution with the revised average value. The conclusion is that the results in this case are stable for search intervals of up to three hours, but detection probability falls off thereafter.

Series VII adjusts search speed and search interval jointly with search interval decreasing by .23 hours for each increase of 1 knot in search speed. Table XVIII lists the results of this first joint experiment. As in Series V stability is indicated for search speed in the range of 12 to 14 knots with no indication of the effect of search interval.

In Series VIII, SI increases .23 hours with each knot increase in search speed. Table XIX lists the results of Series VIII. Figure 23 is a graph of Series VIII data with

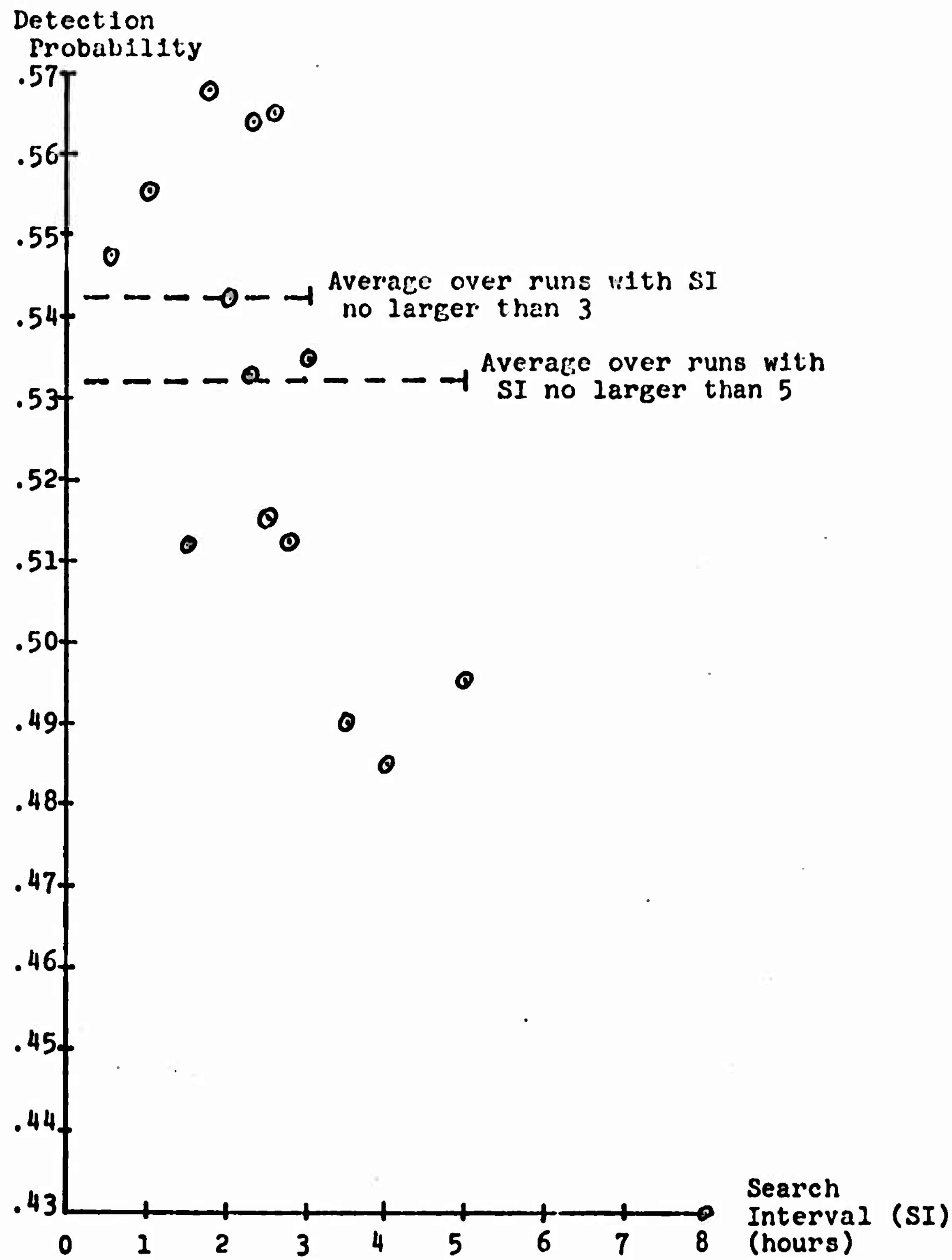


Figure 22. Series VI Data with Partial Sample Averages Shown.

Table XVIII. Series VII Results

Joint Search over search speed and search interval

SS	12	13	14	15	16	20
SI	2.54	2.31	2.07	1.84	1.61	.69
Probability	.5350	.5637*	.5375	.4975	.5075	.4625

* Average of Series II and Series IV results.

Table XIX. Series VIII Results

Joint search over search speed and search interval.

SS	6	7	8	9	10	11
SI	.7	.93	1.16	1.39	1.62	1.85
Probability	.5475	.5675	.5850	.5850	.580	.5850
SS	12	13	14	15	16	20
SI	2.07	2.31	2.54	2.77	3.0	3.92
Probability	.5750	.5650*	.5050	.4850	.4975	.3925

* Average of Series II, IV and VIII

a least squares quadratic regression curve superimposed on the data. Under the assumption that the quadratic curve represents the underlying relationship between search speed, search interval and detection probability, the maximizing values are 8.35 knots and 1.24 hours with an expected detection probability of .5792. These values were entered in the base case.

Series IX is an experiment to find the variable most likely to improve the current base. Table XX lists the base

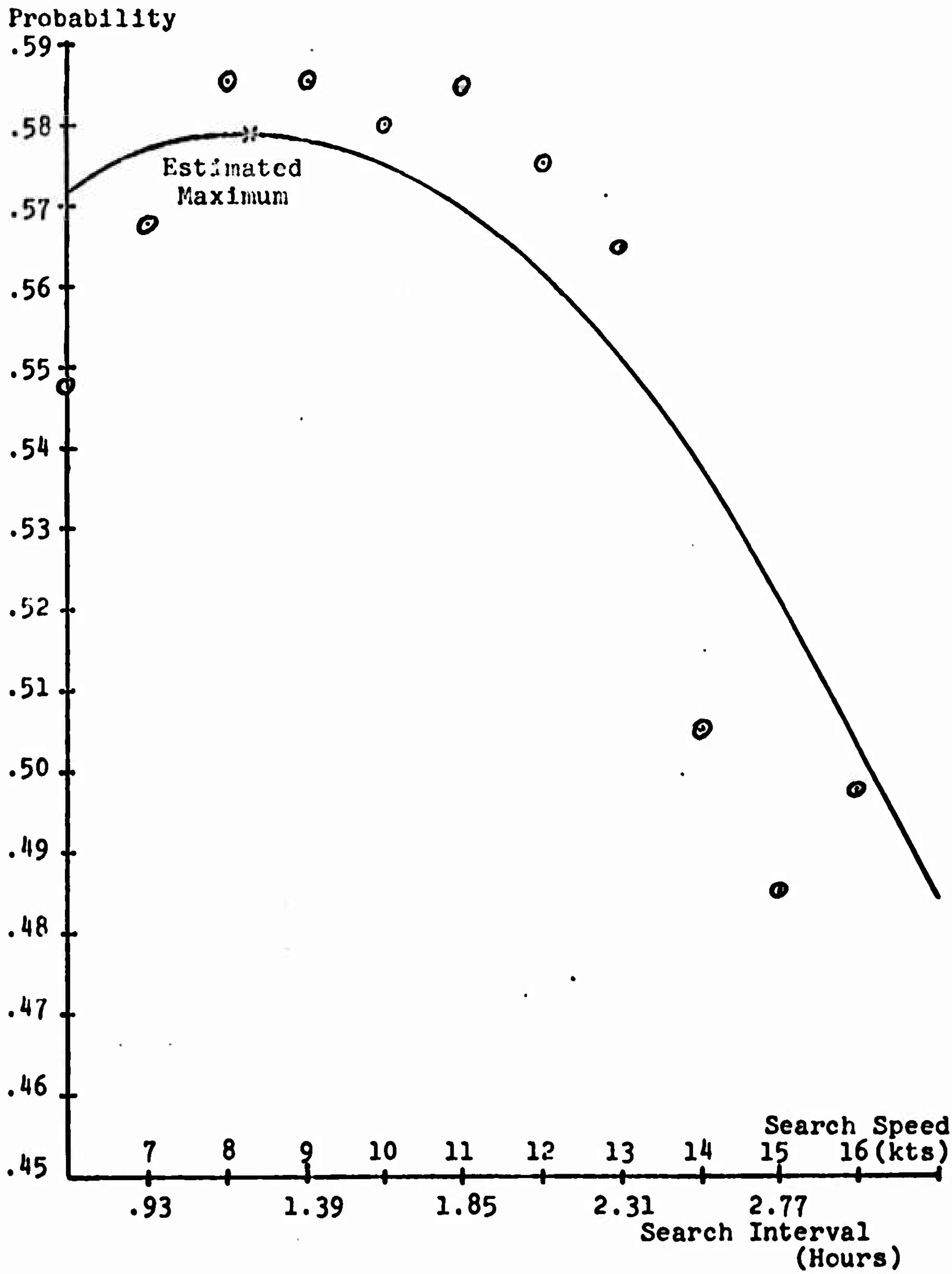


Figure 23. Series VIII Results with Least Squares Quadratic Regression Curve.

Table XX. Series IX Results

Variable	CINT	YTI	SS		SA	SI		SAF	ALL
Base Value	4	400	8.35		25	1.24		4	BASE
Increment	-2	-200	+2.35	-2.35	-2	+.66	-.66	-2	VALUES
Probability	.6175	.520	.545	.5175	.5475	.520	.5525	.5825	.5792*
Difference	+.0383	-.0592	-.0342	-.0617	.0317	-.0592	-.0267	+.0033	.5792*

* Least squares estimate.

values, increments and results for this series. As in Series III, the communications interval offers a significant improvement. Since the value of communications interval for Series IX was its lower bound, no further searching was required, and the base was revised to include CINT=2.

Series X was a search over all variables to find directions of possible improvement and if no improvement is indicated, the range of stability of the solution. Table XXI shows the results from Series X. No improvements were indicated from variation of any of the parameters. The final solution is summarized in Table XXII. The solution appears very insensitive to variation of distance from the northern boundary, YTI, over the range of 200 to 1000 miles. Although most results in this range were greater than the base result, the differences were small and did not indicate a pattern. The loss resulting from increasing communications interval, CINT, from 2 to 4 hours is not statistically significant, while the next step to 6 hours causes a notable

Table XXI. Series X Results

Variable	YTI	YTI	YTI	YTI	YTI	YTI
Value	200	300	500	600	700	800
Probability	.580	.590	.6050	.5725	.6050	.5825
Difference	.0019	.0119	.0269	-.0056	.0269	.0044

Variable	YTI	YTI	SAF	SAF	SAF	SAF
Value	1000	1500	1	2	3	5
Probability	.5875	.5150	.5475	.540	.560	.5125
Difference	.0094	-.0631	-.0306	-.0381	-.0181	-.0656

Variable	SI/SS	SI/SS	SA	CINT	CINT	BASE
Value	1.16/8	1.32/7.7	24	4	6	CASE
Probability	.5125	.5325	.5375	.565	.510	.5781*
Difference	-.0656	-.0456	-.0406	-.0131	-.0131	

* The average value over 1200 trials.

Table XXII. Final Results

Variable	Solution Value	Range of Insensitivity
CINT	2	2,4
YTI	400	200-1000
SS	8.35	*
SA/SI	25/1.24	*
SAF	4	3-4

* The results seem highly sensitive to these parameters.

reduction in detection probability. The speed estimate safety factor, SAF, below 3 knots or greater than 4 knots is associated with a decrease in the final estimate. Moving attacker transit speed, SA, away from its upper bound or adjusting search speed, SS, and search interval, SI, in either direction indicate lower detection probabilities.

The validity of the results should be tested against some of the data estimates. Of particular interest are the surveillance parameters regarding the accuracy of the intelligence, the frequency of the surveillance detections and communications delay, the speed of the target, and the environmental data. It is likely that under differing circumstances, the tactics should be altered from those derived here.

APPENDIX A. LAYER DEPTH ANALYSIS

This appendix deals with the inclusion of sound velocity profile (i.e., layer depth) information in the analysis of a problem. The simple case in which only two operating depths are available is treated first. The method presented is then generalized to the multiple layer depth problem.

VIM was not designed to permit the submarines to change depth to take advantage of various sound conditions. Since a decision to change depth is a rational choice based on the tactical situation, treating it as a random variable would complicate an experiment without increasing the reliability of the results. Further, VIM is not sufficiently sophisticated to make depth change decisions on a rational basis.

Layer depth data includes a propagation loss curve associated with each of the operating depth combinations. The objective of this analysis is to synthesize a single propagation loss table which reflects the expected detection ranges resulting from optimal operating depth policies by both submarines. By considering the depth selection problem as a two person, zero sum game [3] this objective can be realized.

In the two person, zero sum game format the attacker and target are both faced with deciding the proportion of time to spend at each operating depth. A payoff, expected detection range, is associated with each depth depending on the operating depth of the other submarine. Finally, a desirable payoff from the viewpoint of the attacker is a long detection range, whereas this payoff is undesirable for the target.

1. One Layer Problem

Assume that at some given depth there is a layer which either ship can choose to be above or below. From the target radiated noise curve and the attacker self noise curve determine the noise levels for representative speeds and compute the figure of merit for detection of the target by the attacker. Using the figure of merit and the appropriate propagation loss curves determine the maximum ranges of zero signal excess for each combination of operating depths. The problem can be summarized in matrix form as shown in Table A-1.

The value of the game matrix is the expected payoff when both submarines are operating to their best advantage. This is the detection range which will be matched with the figure of merit to form the input propagation loss tables.

The first step in finding the value of the game matrix of Table A-1 is to test for dominance of one operating depth over another for either ship. If the target is always better off operating at depth 1 than if it used depth 2, regardless of the depth of the attacker, then target depth 1 dominates target depth 2 and the column associated with depth 2 may be deleted from the analysis.

Table A-1 One layer, two operating depth game matrix. Entries represent expected detection ranges when the submarines are at the depths in indicated.

		TARGET: Operating depth (1) Above the layer	TARGET: Operating depth (2) Below the layer
ATTACKER	Operating depth (1) Above the layer	R_{11}	R_{12}
ATTACKER	Operating depth (2) Below the layer	R_{21}	R_{22}

Table A-2 Example of two layer, three operating depth game matrix. Entries are the expected detection ranges when the submarines are at the depths indicated.

	TARGET depth 1	2	3
ATTACKER 1	10	12	14
ATTACKER 2	15	13	9
ATTACKER 3	13	17	12

In Table A-1, R_{11} would be less than R_{12} and R_{21} would be less than R_{22}. Having eliminated one possible decision for the target, the attacker may now choose the operating depth corresponding to the larger of R_{11} and R_{12} which is the value of the game.

For example, if the actual matrix of detection ranges were

		Target Depth 1	Target Depth 2
Attacker	1	10	15
	2	12	13

then the target would always select depth 1 and the attacker would remain in depth 2. Expected detection range would be 12 miles.

Similarly, if the matrix were

		Target Depth 1	Target Depth 2
Attacker	1	8	10
	2	12	11

then attacker's depth 2 is always better than depth 1, and the target would choose depth 2 resulting in an expected detection range of 11 miles.

If it is established that no dominance exists between the rows or columns of the matrix, the solution for the expected detection range, R, is found in reference [4] and is given by

$$R = \frac{R_{11}\,|R_{21} - R_{22}| + R_{21}\,|R_{11} - R_{12}|}{|R_{21} - R_{22}| + |R_{11} - R_{12}|}$$

2. Multiple Layer Problem

Where more than two operating depths are permitted the nature of the problem is unchanged but the mathematics required for the solution are more complex. The detection matrix for each combination of depths is now N × N, where there are N possible operating depths. For the purposes of this discussion let N=3 and assume Table A-2 is the expected detection range matrix for a given figure of merit. As in the one layer, two operating depth case the first step is to test for dominance. Check to see if each of the entries from a row or column are preferred to the corresponding values of another row or column. If so, delete the dominated row or column from the analysis. In this way it may be possible to reduce the problem to simpler form. In the example, Table A-2, there is no dominance.

After removing dominated rows or columns, test the matrix for a saddle point. For each protagonist list the worst possible outcome from each possible decision. By selecting the operating depth which results in the least undesirable of these outcomes each submarine is guaranteed that the expected detection range will never be worse than that value regardless of the actions of the other. If the range so chosen is the same for both submarines their decisions will actually result in that expected value and a saddle point has been found.

In the example, Table A-2, let $A_i = \min_j R_{ij}$ and $T_j = \max_i R_{ij}$.

$$A_1 = \min (10, 12, 14) = 10$$

$$A_2 = \min (15, 13, 9) = 9$$

$$A_3 = \min (13, 17, 12) = 12$$

$$T_1 = \max (10, 15, 13) = 15$$

$$T_2 = \max (12, 13, 17) = 14$$

$$T_3 = \max (14, 9, 12) = 14$$

Let $A^* = \max_i A_i = \max (10, 9, 12) = 12$

and $T^* = \min_j T_j = \min (15, 17, 14) = 14$.

Since $A^* \neq T^*$, the example does not have a saddle point.

Whether or not the above operations produced any simplifications, the problem can be formulated as a linear program. The general form is

$$\text{maximize } R$$

$$\text{subject to } R - R_{1k}x_1 - \ldots - R_{Nk}x_N \leq 0, \quad k=1,\ldots,N$$

$$x_1 + \ldots + x_N = 1$$

$$R, x_1, \ldots, x_N \geq 0$$

where x_i represents the proportion of time the attacker spends at depth i. The actual values of x are not important for this analysis. The value of R will be the expected detection range at the given figure of merit. In the example, Table A-2, the problem can be written maximize R

$$
\begin{aligned}
\text{subject to } R - 10x_1 - 15x_2 - 13x_3 &\leq 0 \\
R - 12x_1 - 13x_2 - 17x_3 &\leq 0 \\
R - 14x_1 - 9x_2 - 12x_3 &\leq 0 \\
x_1 + x_2 + x_3 &= 1 \\
R, x_1, x_2, x_3 &\geq 0
\end{aligned}
$$

Solution to this problem by the simplex method is explained in reference [4] and programs to carry out the computations are available at many computer facilities.

By selecting seven values of figure of merit near those values expected during the execution of the experiment, a propagation loss table will be developed which reflects optimal submarine operating depth selection.

APPENDIX B. PROGRAM LISTING

1. Alphabetical subroutine index

Program name

Alphabetical index to Appendix B (cont.)

Program name

APPENDIX B. PROGRAM LISTING

MAIN

```
      COMMON / INP1 / NTRIAL, M, N, IOPT, NOPT, NCYCR, NEVD,
     2               NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2               SS, SA, VI, CAI, SI, AMB, SIGMA,
     3               EVANG, EVSPD, SE, CE, SAF, GAINA,
     4               GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INP3 / CST(50), SPT(50), TT(50), PINT(50),
     2               SPAX(50), SPAY(50), TI(100), RINP(100)
     3              ,BINP(100), CINP(100), SINP(100),
     4               WORDS (40)
      COMMON / INP4 / VN(7), SNA(7), RNA(7), STN(7), SNT(7),
     2               RNT(7), PLCS(7), RDET(7)
      COMMON / UPD / DT, PDW,DR, D, NOCZ, INCZ
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / CRSE / CA, CT
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / LIST / NTYPE(160), TE(160), K, KTEMP, TD,
     2               TDA, TA, MI, TCZ
      COMMON / INTGRU / I, J, JJ, XORIG, YORIG, TORIG,
     2                 XDINT(100), YDINT(100), SDINT(100),
     3                 CDINT(100), TDINT (100), EVADE
      COMMON / INTCOM / TCUR, STINT, CTINT, XTE, YTE, IRUN,
     2                 TOR, NEWINT, NOINT
      COMMON / SPEC1 / R, V, ST, PROP, TF
      COMMON / SPEC2 / PT, ICOUNT
      COMMON / DATA / NTF, NTE, NREP, NIOT, NEDET, NDSTA,
     2               NDTRA, NCDTR, NCDST, NSPACE, KDATA,
     3               NSSW, NEVADE, NCDT(100), NCDS(100),
     4               NDATA, U, SSW,        PRO, PDMAX, PDT,
     5               PDS, PSMAX, PTMAX, TDET(500),
     6               TCURD(100), STIME, TCRD(100),
     7               DELONE(100), DELTWO(100), PRDET(150),
     8               PMAX(100), PTRANS(100),PSERCH(100),
     9               PTTIME(150), PSTIME(150), NCZ, INTCZ,
     1               NOCZ, CZTIME (100)
C     READ ENVIRONMENTAL DATA
      IRUN = 1
      CALL INOUT
C     READ TACTICAL DATA
    7 CONTINUE
      CALL INOUT2
```

```
      NTEMP = NREP + 1
      IF ( NDATA .EQ. 99999 ) GO TO 508
C     TEST FOR COMPUTED OR INPUT INTELLIGENCE TIMES
      NNCOMP = 2 - NCOMP
      IF ( NOPT ) 21, 19, 21
C     COMPUTE INTELLIGENCE TIMES
   21 CALL REVENT ( PINT, MI,TT, TINT, TEND, NNCOMP, TI, N , NCYCR )
   19 IF ( NREP ) 13, 13, 14
   14 GO TO  ( 16, 16, 16, 16, 31) , IOPT
C     WRITE THE INPUT DATA
   13 CONTINUE
      U = 0.
C     U IS A TEST VALUE FOR NOPT / NCOMP COMPATABILITY
      CALL INOUT3
      IF ( U .EQ. 0. ) GO TO 31
      GO TO 7
C     WRITE THE COMPUTED INTELLIGENCE TIMES
   16 CONTINUE
      CALL INOUT4
      GO TO 31
C     INITALIZE FOR TRIAL
   17 GO TO ( 37, 37, 30, 37, 35 ), IOPT
   37 CONTINUE
         NTEMP = NREP + 1
      WRITE ( 6, 700 ) NDATA, NTEMP, KDATA
      KDATA = KDATA + 1
      NSPACE = 0
C     TEST FOR NEW PAGE
   30 IF ( NSPACE - 2 ) 39, 36, 36
   36 CONTINUE
      WRITE ( 6, 700 ) NDATA, NTEMP, KDATA
      KDATA = KDATA + 1
      NSPACE = 0
C     NSPACE IS USED TO SPACE DETAILED BATTLE HISTORY
   39 NTEMP = NREP + 1
      WRITE ( 6, 770 ) NTEMP
   35 CONTINUE
   38 IF ( NOPT ) 21, 31, 31
   31 CONTINUE
      CALL INOUT8
      FINAL = TI (N) + TL + CINT

C     COMMENCE NEW EVENT
  299 NEWINT = 0
      NDCZ = 0
C     NEWINT IS AN OUTPUT SWITCH. NEWINT = 1 WHEN ATTACKER RECEIVES
C     NEW INTELLIGENCE.
      IJK = 0
```

```
C     IJK IS A FLAG INDICATING ATTACKER IS LEAVING SEARCH STATION
C     SELECT NEXT EVENT
      NN = NTYPE ( KTEMP )
      PT = TE ( KTEMP )
      CALL UPDATE
      PD = PDW
      IF ( PT .LE. FINAL ) GO TO 301
      IF ( SSW .EQ. 0. ) GO TO 301
      IF ( PD .GT. 0. ) GO TO 301
      IF (( XT - XA ) * STX + ( YT - YA ) * STY .GT. 0.) GO TO 327
  301 GO TO ( 310, 316, 305, 304, 323, 317, 327, 340 ), NN
C     NEW TARGET LEG. CEASE EVASION. NTYPE = 1
  310 I = I + 1
      KTEMP = KTEMP + 1
      ICOUNT = -2
      GO TO ( 335, 335, 314, 335, 314 ), IOPT
  335 WRITE ( 6, 767 ) PT
  314 CT = RAD (CST(I))
      ST = SPT(I)
      IF ( NRTT .EQ. 1 ) CT = CT + RAND ( NCYCR ) * CE
      IF ( NRTT .EQ. 1 ) ST = ST + RAND ( NCYCR ) * SE
      EVADE = 0.
      NOINT = 1
      GO TO 100
C     INTELLIGENCE DETECTION.  NTYPE = 2
  316 J = J + 1
      KTEMP = KTEMP + 1
      NOINT = 1
      GO TO ( 336, 336, 410, 336, 410 ), IOPT
  336 WRITE ( 6, 769 ) PT
  410 CALL INTDET
      IF ( CINT .GT. 0. ) GO TO 300
      TIME = PT + TL
      CALL RPLACE ( 6, TIME )
      GO TO 300
C    DETECTION PROBABILITY EVENT.  NTYPE = 3
  305 NR = 2
      IF ( SSW .EQ. 0. ) GO TO 309
      IF ( PD .LE. PMOST) GO TO 497
      IF ( ICZ .EQ. 1 .AND. INCZ.EQ. 1 ) GO TO 497
C     SAVE TEMPORARY ON STATION DATA
  302 PMOST = PD
      TIME =  PT
      CURT = TCUR
      RT = TOR
```

```
      DEL1 = TOR - TCUR
      DEL2 = PT - TOR
      GO TO 498
C     COUNTERDETECTION EVENT. EITHER COMMENCE OR CEASE EVASION
C     NTYPE = 4
  304 NOINT = 1
C     NOINT SPECIFIED INTELLIGENCE STATUS. NOINT = 0 ALLOWS ATTACKER TO
C     RECEIVE LATEST INTELLIGENCE.
      IF ( EVADE ) 321, 321, 322
C     COMMENCE EVASION
  321 EVADE = 1.
      TE ( KTEMP ) = PT + ETIME
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      NTE = NTE + 1
      GO TO ( 332, 332, 333, 332, 333 ), IOPT
  332 WRITE ( 6, 772 ) PT
  333 CALL AVOID ( NEVD )
      IF ( SSW ) 330, 330, 331
  330 NCDTR = NCDTR + 1
      GO TO 100
  331 NCDST = NCDST + 1
      GO TO 100
C     CEASE EVASION
  322 GO TO ( 334, 334, 314, 334, 314    ), IOPT
  334 WRITE ( 6, 773 ) PT
      GO TO 314

C     ATTACKER COURSE CHANGE EVENT. NTYPE = 5
  323 NOINT = 1
      GO TO ( 338, 338, 306, 338, 306 ), IOPT
  338 WRITE ( 6, 765 ) PT
  306 IF  (SSW) 307, 307, 308
C     ATTACKER ARRIVES ON STATION.
  307 SSW = 1.
      V = SS
      CA = CTINT + 1.5708
      TE ( KTEMP ) = PT + SI/ 2.
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      PMOST = 0.
      IF ( CINT .EQ. 0. ) GO TO 100
  318 CTTEMP = CTTEMP + 2
      IF ( CTTEMP .LT. PT ) GO TO 318
      CALL RPLACE ( 6, CTTEMP )
      GO TO 100
C     ATTACKER COMPLETED SEARCH LEG.
  308 CA = CA + 3.1416
      TE ( KTEMP ) = PT + SI
```

```
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      GO TO 100

C     COMMUNICATIONS PERIOD.   NTYPE = 6
  317 CONTINUE
      CTTEMP = PT
      TEMP = PT + CINT
      IF ( SSW .EQ. 1 ) TEMP = PT + 2.
      IF ( CINT .EQ. 0. ) TEMP = PT + 1000.
      GO TO ( 337, 337, 339, 337, 339 ), IOPT
  337 WRITE ( 6, 768 ) PT
  339 CONTINUE
C     PROVIDE LATEST INTELLIGENCE TO ATTACKER
      CALL PROINT
      IF ( IRUN .EQ. 1 .AND. CINT .GT. 0. ) TEMP = PT + CINT
      TE ( KTEMP ) = TEMP
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      IF ( IRUN .NE. 1 ) GO TO 300
C     DETERMINE ATTACKER COURSE AND TIME TO INTERCEPT TARGET
  402 CONTINUE
      INTCZ = 0
  401 CALL PIM ( XA, YA, XTE, YTE, V, STINT, CTINT, XI, YI, CA, TC, ER
      IF ( ER ) 407, 407, 801
  407 TA = PT + TC
      CALL RPLACE ( 5, TA )
      NR = 4
      IF  ( SSW .EQ. 0. ) GO TO 100
      IJK = 1
      PDTEMP = PD
      PD = PMOST
      GO TO 309

C     END OF TRIAL. NTYPE = 7
  327 CONTINUE
      TEST = SSW
      IJK = 1
      PDTEMP = PD
      PD = PMOST
      NR = 5
      IF ( IOPT .LT. 5 ) NR = 6
      IF ( SSW .EQ. 1 ) GO TO 309
      IF ( IOPT .EQ. 5 ) GO TO 500
  328 NTEMP = NREP + 1
      WRITE ( 6, 758 ) PT, NTEMP
      SSW = TEST
  500 CONTINUE
      CALL INOUT6
      CALL INOUT5
```

```
      GO TO 499
C     CONVERGENCE ZONE EVENT.  NTYPE = 8
  340 CONTINUE
      IF ( NCCZ .EQ. 1 ) GO TO 341
      NOCZ = 1
      IF ( IOPT .EQ. 5 .OR. IOPT .EQ. 3 ) GO TO 343
      WRITE ( 6, 760 ) PT
  343 IF ( ICZ .EQ. 0 ) GO TO 342
      IF ( RNG ( NCYCR ) .GT. PD ) GO TO 344
      CALL CZINT
      INTCZ = 1
      TCUR = 0.
      TOR = 0.
      CZTIME ( NTEMP ) = PT
      V = SA
      GO TO 401
  341 CONTINUE
C     A PREVIOUS CONVERGENCE ZONE EVENT HAS BEEN EXECUTED
      TE ( KTEMP ) = TEND + 101.
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      GO TO 299
  342 CONTINUE
      TE ( KTEMP ) = TEND + 101.
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      IF ( PD .LE. 0. ) GO TO 300
      IF ( PD .GE. PDMAX ) NCZ = 1
      IF ( PD .GE. PDMAX ) CZTIME ( NTEMP ) = PT
      NDCZ = 1
      NR = 7
      GO TO 309
  344 CONTINUE
C     NO CONVERGENCE ZONE INTELLIGENCE AT THIS TIME
      TE ( KTEMP ) = TEND + 101.
      CALL ORDER2 ( TE, NTYPE, KTEMP, K )
      GO TO 300
C     UPDATE DETECTION PROBABILITY COUNTERS
  309 CONTINUE
      IF ( PD. LE. 0. ) GO TO 496
      IF ( SSW .EQ. 0.    .AND.
     2     ICZ .EQ. 1     .AND.
     3     INCZ .EQ. 1 ) GO TO 498
      NTOT = NTOT + 1
      NTEMP = NREP + 1
      PRDET (NTOT) = PD
      IF ( IOPT .GE. 4 ) GO TO 311
      PTTIME ( NTOT ) = 0.
```

```
      IF ( SSW .EQ.  0. ) PTTIME ( NTOT ) = PT
      PSTIME ( NTOT ) = 0.
      IF ( SSW .EQ.  1. ) PSTIME ( NTOT ) = TIME
  311 PRD = PD * ( 1. - PRD ) + PRD
      IF ( SSW .EQ. 0. )
     2PDT = PDT + ( 1. - PDT ) * PD
      IF ( SSW .EQ. 1. ) PDS = PDS + (1.-PDS ) * PD
      IF (( PD .GT. PSMAX ) .AND. ( SSW.EQ. 1. )) PSMAX = PD
      IF (( PD .GT. PTMAX ) .AND. ( SSW.EQ. 0. )) PTMAX = PD
      IF ( PDMAX .GE. PD ) GO TO 496
      PDMAX = PD
      NSSW = SSW
      NEVADE = EVADE
      IF ( NOCZ .EQ. 0 ) NCZ = 0
      IF ( NDCZ .EQ. 0 ) CZTIME ( NTEMP ) = 0.
      IF ( INTCZ .EQ. 0 .AND. ICZ .EQ. 0 ) CZTIME (NTEMP ) = 0.
      IF ( NDCZ .EQ. 1 ) GO TO 312
      IF ( SSW .EQ. 1.) GO TO 350
C     COMPILE TRANSIT STATISTICS
  312 CONTINUE
      TDET ( NTEMP) = PT
      TCURD (NTEMP)= TCUR
      TORD (NTEMP)= TOR
      DELONE (NTEMP)= TOR - TCUR
      DELTWO (NTEMP)= PT - TOR
      GO TO 496
C     COMPILE ON STATION STATISTICS
  350 TDET ( NTEMP ) = TIME
      TCURD ( NTEMP ) = CURT
      TORD ( NTEMP ) = RT
      DELONE ( NTEMP ) = DEL1
      DELTWO ( NTEMP ) = DEL2
  496 CONTINUE
      IF ( NOCZ .EQ. 0 ) SSW = 0
  498 CONTINUE
      GO TO ( 103, 497, 104, 100, 500, 328, 300 ), NR
  497 IF ( PRD .GE. 1 ) GO TO 327
      CALL RPLACE ( 3, PT + 500. )
      GO TO ( 352, 352, 300, 352, 300 ), IOPT
  352 WRITE ( 6, 774 ) PT
      GO TO 300

C     CALCULATE DETECTION RANGES
  100 VX = V * SIN (CA)
      VY = V * COS ( CA )
      STX = ST * SIN ( CT )
      STY = ST * COS ( CT )
      IF ( IJK .EQ. 1 ) PD = PDTEMP
```

```
      CALL DETECT (0.)
      PDW = PDET (D)
      IF ( PDW .GT. PD ) PD = PDW
      PDW = PD
      DR1= ( XT-XA ) * ( VX-STX ) + ( YT-YA ) * ( VY-STY )
      IF ( DR1 .LT. 0. ) GO TO 105
      CALL CPAT
      TD = TF + PT
      GO TO 103
      TD = PT
      IF ( DR .LT. 0. ) TD = TD + 101.
  103 CONTINUE
      CALL RPLACE ( 3, TD )
      NR = 3
      IF ( SSW .LE. 0. ) GO TO 104
      IF ( PD .GT. PMOST) GO TO 302
  104 CONTINUE
      IF ( CZR .EQ. 0. ) GO TO 106
      DR = DR1
      CALL CZDET
      TCZ = PT + TF
      CALL RPLACE ( 8, TCZ )
  106 CONTINUE
      IF (( EVADE .GE. 1. ) .OR. ( NEVD .EQ. 5 )) GO TO 300
  101 CALL DETECT ( 1. )
      CALL FIND
      TDA = TF + PT
      CALL RPLACE ( 4, TDA )
      GO TO 300
C     ERROR ROUTINE
  800 WRITE (6, 756)
      IRUN = 7
      CALL INOUT
      GO TO 507
  801 IF ( TCUR .GE. TI (N) ) GO TO 802
      CA = CTINT
      TC = TEND + 500.
      GO TO 407
  802 CONTINUE
      IF ( NSUP .EQ. 0 ) WRITE ( 6, 762 ) NTEMP
      IF ( SSW .EQ. 0. ) GO TO 500
      PD = PMOST
      NR = 5
      GO TO 309
C     END OF EVENT
  300 CONTINUE
```

```
      CALL INOUT6
  499 GO TO ( 299, 17, 507  ) , IRUN
C     GAME COMPLETE.  WRITE SUMMARY
  507 CONTINUE
      CALL INOUT7
      GO TO 7

  700 FORMAT ( '1', 18X, '   DATA SET 'I5, '    TRIAL 'I5, '    PAGE ' I5
     2   ///   )
  756 FORMAT (/// 17H EVENT LIST ERROR  )
  758 FORMAT ( /// 16H PROBLEM TIME = F6.2, 17H    END OF TRIAL I3 )
  760 FORMAT ( // ' PROBLEM TIME = ' F6.2, '  CONVERGENCE ZONE EVENT ')
  762 FORMAT ( / 66H UNABLE TO OVERTAKE TARGET DUE TO SPEED DIFFERENTIA
     2. ABORT TRIAL    I3  )
  765 FORMAT ( // 15H PROBLEM TIME = F6.2, 21H    NEW ATTACKER LEG )
  767 FORMAT ( // 16H PROBLEM TIME = F6.2, 19H    NEW TARGET LEG )
  768 FORMAT ( // 16H PROBLEM TIME = F6.2, 25H    ATTACKER COMM. PERIOD
  769 FORMAT (  // 16H PROBLEM TIME = F6.2, 23H    INTEL. DETECTION )
  770 FORMAT (/// 16H COMMENCE TRIAL  I3 //  )
  772 FORMAT( // 16H PROBLEM TIME = F6.2,27H    TARGET EVADING ATTACKER
  773 FORMAT ( // 16H PROBLEM TIME = F6.2,39H    EVASION COMPLETE. CONT
     2NUE TRANSIT  )
  774 FORMAT ( // ' PROBLEM TIME = ' F6.2,'   POSSIBLE DETECTION OF TAR
     2ET '  )
  508 STOP
      END
```

```
      SUBROUTINE INOUT
      COMMON / INP1 / NTRIAL, M, N, IOPT, NOPT, NCYCR, NEVD,
     2                NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAE, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INP3 / CST(50), SPT(50), TT(50), PINT(50),
     2                SPAX(50), SPAY(50), TI(100), RINP(100)
     3               ,BINP(100), CINP(100), SINP(100),
     4                WORDS (40)
      COMMON / INP4 / VN(7), SNA(7), RNA(7), STN(7), SNT(7),
     2                RNT(7), PLOS(7), RDET(7)
      COMMON / UPD / OT, PD ,DR, D, NOCZ, INCZ
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / CRSE / CA, CT
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / LIST / NTYPE(160), TE(160), K, KTEMP, TD,
     2                TDA, TA, MI, TCZ
      COMMON / INTGRU / I, J, JJ, XORIG, YORIG, TORIG,
     2                  XOINT(100), YDINT(100), SDINT(100),
     3                  CDINT(100), TDINT (100), EVADE
      COMMON / INTCOM / TCUR, STINT, CTINT, XTE, YTE, IRUN,
     2                  TOR, NEWINT, NOINT
      COMMON / SPEC1 / R, V, ST, PROP, TF
      COMMON / SPEC2 / PT, ICOUNT
      COMMON / DATA / NTF, NTE, NREP, NTOT, NEDET, NDSTA,
     2                NDTRA, NCDTR, NCDST, NSPACE, KDATA,
     3                NSSW, NEVADE, NCDT(100), NCDS(100),
     4               NUMBER, U, SSW,            PRD, PDMAX, PDT,
     5                PDS, PSMX,  PTMX,  TDET(500),
     6                TCURD(100), STIME, TORD(100),
     7                DELONE(100), DELTWO(100), PRDET(150),
     8                PMAX(100), PTRANS(100),PSERCH(100),
     9                PTTIME(150), PSTIME(150), NCZ, INTCZ,
     1                NDCZ, CZTIME (100)
      DIMENSION NDET (100), PSMAX (100), PTMAX (100), PDETMX (100)
      DIMENSION PTEND ( 100), PDSTA (100), PDTRA (100)
      DIMENSION PTRIAL (100)
      DIMENSION C ( 27 ), NO (13 )
      EQUIVALENCE ( C(1), TEND )
      EQUIVALENCE ( NO (1), NTRIAL )
```

```
C     ENVIRONMENTAL DATA
C     TITLE CARD
      READ ( 5, 718 ) ( WORDS (I), I = 1, 20 )
C     ATTACKER NOISE CURVES
      READ (5, 702) ( VN (L), L = 1, 7 )
      READ ( 5, 702 ) ( SNA (L) , L = 1, 7 )
      READ ( 5, 702 ) ( RNA (L) , L = 1, 7 )
C     TARGET NOISE CURVES
      READ (5, 702) ( STN (L), L = 1, 7 )
      READ ( 5, 702 ) ( SNT (L) , L = 1, 7 )
      READ ( 5, 702 ) ( RNT (L) , L = 1, 7 )
C     PROPAGATION LOSS CURVES
      READ (5, 702) ( PLOS (L), L = 1, 7 )
      READ (5, 702) ( RDET (L), L = 1, 7 )
C      INITIALIZE FOR DATA INPUT
      EVANG = 0.
      CE = 0.
      NI = 0
      NJ = 0
      MJ = 0
      IOP = 5
      RETUPN
```

INOUT2

```
C     TACTICAL DATA SET DESIGNATION
      ENTRY INOUT2
    7 READ ( 5, 701 ) NUMBER, NCYCR, NOC, NC
    7 READ ( 5, 701 ) NUMBER, NCYCR, NCYR, NOC, NC
      NCYCR = NCYCR * 100000 + NCYR
      IF ( NUMBER .EQ. 99999 ) RETURN
      KDATA = 1
C     KDATA IS THE PAGE COUNTER
      READ ( 5, 718 ) ( WORDS (I), I = 21, 40 )
C      OPTION INPUTS
      IOPT = IOP
      N = NI
      IF ( NOC .EQ. 99 ) GO TO 10
      IF ( NOC .EQ. 0 ) GO TO 11
      READ ( 5, 701 ) ( J, NO (J), I = 1, NOC )
      GO TO 10
   11 CONTINUE
      READ ( 5, 701 ) NTRIAL, M, N, IOPT, NOPT,NCY,NCR,NEVD, NCOMP ,
     2          INRAND, NC, NSUP, NRTT, ICZ
      NCYCR = NCY * 100000 + NCR
   10 CONTINUE
      IOP = IOPT
      IF ( M .GT. 0 ) MI = M
```

```
      NI = N
      IF ( N .GT. 0 ) NJ = N
      EVANG = DEG ( EVANG )
      CE = DEG ( CE )
      IF ( NC .EQ. 99 ) GO TO 8
      IF ( NC .EQ. 0 ) GO TO 4
      READ ( 5, 719 ) ( J, C (J), I = 1, NC )
      GO TO 8
C     SITUATION INPUTS
    4 READ ( 5, 702 ) TEND, CINT, XTI, YTI, TL, TINT, ETIME
      READ ( 5, 702 ) SS, SA, VI, CAI, SI, AMB,  SIGMA
      READ ( 5, 702 )    EVANG, EVSPD, SE, CE, SAF, GAINA, GAINT
      READ ( 5, 702 ) CZR, CZW, CZSE, CZCE, CZBE, CZRE
    8 CONTINUE
      NCYC = NCYCR
C     TARGET TRACK INPUTS
      IF ( M .GT. 0 )
     2READ ( 5, 703 ) ( CST (I), SPT (I), TT (I), PINT (I), SPAX (I),
     3                 SPAY (I), I = 1, M )
C     INTELIGENCE INPUTS
      IF ( N .GT. 0 )
     2READ ( 5, 715 ) ( TI (J), RINP (J), BINP (J), CINP (J), SINP (J),
     3                  J = 1, NJ )
C     INITIALIZE THE RANDOM NUMBER GENERATOR.
      NCYCR = NCYCR * 2 + 1
      NREP = 0
C     NREP IS THE TRIAL COUNTER
      NTEMP = NREP + 1
      TNOW = 0.
      X2 = XTI
      Y2 = YTI
      X1 = 0.
      Y1 = 0.
      RSTART = SQRT (( X2 - X1 ) ** 2 + ( Y2 - Y1 ) ** 2 )
      DO 3 I = 1, M
      XBEST = 0.
      YBEST = 0.
      ER = 0.
      CP = RAD ( CST (I) )
      SP = SPT (I)
      CALL PIM( X1, Y1, X2, Y2, SA, SP, CP, XBEST, YBEST,
     2             CB, TBEST )
      IF ( ER .EQ. 1 ) RETURN
      IF ( TBEST .LE. TT (I) - TNOW ) GO TO 2
      TNOW = TT (I) - TNOW
      X1 = X1 + SIN (CB)* SA * TNOW
      Y1 = Y1 + COS (CB)* SA * TNOW
      X2 = X2 + SIN (CP) * SP * TNOW
```

```
      TNOW = TT (I)
    3 CONTINUE
    2 TBEST = TBEST + TNOW
      RETURN
```

INOUT3

```
C     WRITE INPUT DATA
   13 CONTINUE
      ENTRY INOUT3
      WRITE ( 6, 700 ) NUMBER, NTEMP, KDATA
      KDATA = KDATA +1
      WRITE ( 6, 704 ) NUMBER
      WRITE ( 6, 720 )
      WRITE (6 , 780 )  ( WORDS (I), I = 1, 20 )
      WRITE (6, 711)
      WRITE (6, 702) (VN (L), L = 1, 7 )
      WRITE ( 6, 702 ) ( SNA (L), L = 1, 7 )
      WRITE ( 6, 702 ) ( RNA (L), L = 1, 7 )
      WRITE (6, 712)
      WRITE (6, 702) (STN (L), L = 1, 7 )
      WRITE ( 6, 702 ) ( SNT (L), L = 1, 7 )
      WRITE ( 6, 702 ) ( RNT (L), L = 1, 7 )
      WRITE (6, 713)
      WRITE (6, 702) ( PLOS (L), L = 1, 7 )
      WRITE (6, 702) ( RDET (L), L = 1, 7 )
      WRITE (6,780 ) ( WORDS (I) , I = 21, 40)
      WRITE ( 6, 721 )
      WRITE (6, 706) NTRIAL , M, NI,IOPT, NOPT, NCYC  , NEVD, NCOMP ,
    2     INRAND, NC, NSUP, NRTT, ICZ
      WRITE ( 6, 722 )
      WRITE ( 6, 707 ) TEND, CINT, XTI, YTI, TL, TINT, ETIME
      WRITE ( 6, 703 ) SS, SA, VI, CAI, SI, AMB, SIGMA
      WRITE ( 6, 710 ) EVANG, EVSPD, SE, CE, SAF, GAINA, GAINT
      WRITE ( 6, 716 ) CZR, CZW, CZSE, CZCE, CZBE, CZRE
      WRITE (6, 709)
      WRITE ( 6, 703 )(CST (I), SPT (I), TT (I), PINT (I), SPAX (I),
    2                 SPAY (I),I= 1, MI)
      IF ( NCOMP .LE. 2 ) GO TO 16
      IF ( NOPT .EQ. 0 ) GO TO 19
   20 WRITE ( 6, 717 ) NUMBER
      U = 1.
      RETURN
   19 WRITE ( 6, 705 )
      WRITE ( 6, 714 )
      WRITE ( 6, 715 ) ( TI (J), RINP (J), BINP (J), CINP (J), SINP (J)
    2                  J = 1, NJ )



      IF ( NRTT .EQ. 1 ) CT = CT + RAND ( NCYCR ) * CE
      ST = SPT(I)
      IF ( NRTT .EQ. 1 ) ST = ST + RAND ( NCYCR ) * SE
```

```
      CA = RAD (CAI)
      V = VI
C     CT, ST, CA, V ARE TARGET AND ATTACKER COURSE AND SPEED.
      SSW = 0.
      NSSW = 2
      EVADE = 0.
      NEVADE = 0
C     SSW IS THE ATTACKER ON STATION SWITCH, SSW=1, ATTACKER IS
C     ON STATION
C     EVADE IS THE TARGET EVASION SWITCH. IF EVADE = 1, TARGET IS
C     EVADING.
      PT = 0.
C     PT IS PROBLEM TIME
      TCUR = 0.
C     TCUR IS THE TIME OF INTELLIGENCE NOW IN USE
      L = NREP + 1
      NTOT = 0
      TDET (L) = 0.
      TCURD (L) = 0.
      TCRD (L) = 0.
      DELONE (L) = 0.
      DELTWO (L) = 0.
      CZTIME (L) = 0.
C     NTOT IS THE TOTAL NUMBER OF DETECTIONS BY ATTACKER
C     TDET IS THE LIST OF DETECTION TIMES DURING THE GAME
C     TCURD IS THE INTELLIGENCE TIME ASSOCIATED WITH TDET. TORD IS THE
C     DELTWO IS TDET - TORD.
      NCDTR = 0
      NCDST = 0
C     NCDST AND NCDTR ARE COUNTER-DETECTION COUNTERS (ON STATION AND
C     TRANSIT)
      NOCZ = 0
C     NOCZ IS SET TO 1 AT A CONVERGENCE ZONE EVENT, AND IS SET TO
C             ZERO WHEN THE ATTACKER LEAVES THE CONVERGENCE ZONE.
      NCZ = 0
C     NCZ IS SET TO 1 WHEN THE MAX DETECTION PROBABILITY IS FROM A
C             CONVERGENCE ZONE EVENT
      INTCZ = 0
C     INTCZ IS SET TO ONEIF THE MOST RECENT INTELLIGENCE IS FROM
C            A CONVERGENCE ZONE.
      NTE = 0
C     NTE IS THE NUMBER OF TARGET EVASIONS THIS TRIAL
      PRD = 0.
      PDMA  = 0.
      PSMX = 0.
      PTMX = 0.
      PDT = 0.
      PDS = 0.
```

```
C     PRD, PDT, PDS ARE CUMULATIVE DETECTION PROBABILITIES: OVERALL,
C     TRANSIT AND STATION RESPECTIVELY.
C     PDMAX IS THE MAXIMUM SINGLE DETECTION PROBABILITY FOR THE TRIAL.
C      PSMAX, PTMAX ARE MAXIMUM ON STATION AND TRANSIT DETECTION
C      PROBABILITIES
      TA = TEND + 101.
      OT = 0.
C     TA IS TIME FOR ATTACKER TO CHANGE COURSE
C     OT IS TIME OF PREVIOUS EVENT
      XA = 0.
      YA = 0.
      XT = XORIG
      YT = YORIG
C     XA, YA, XT, YT ARE ATTACKER AND TARGET POSITIONS.
      ICOUNT = 1
C     ICOUNT IS USED TO CATALOG INTELLIGENCE POSITIONS FOR OPTION 1.
C     ICOUNT = 1 INDICATES FIRST INTELLIGENCE OF TRIAL. ICOUNT NEGATIVE
C     IS USED WITH TARGET COURSE CHANGES.  ICOUNT = 0 CALLS FOR AN
C     IMPROVED INTELLIGENCE DETERMINATION.
      STX = ST * SIN ( CT )
C     COMPUTE TARGET AND ATTACKER VELOCITY VECTORS
      STY = ST * COS ( CT )
C     VX, VY, STX, STY ARE ATTACKER AND TARGET VECTOR COMPONENTS
      VY = V * COS ( CA )
      VX = V * SIN (CA)
C     ESTABLISH INITAL DETECTION EVENTS
      CALL DETECT (0.)
      CALL CPAT
      TD = TF
C     TD IS TIME OF DETECTION
      TDA = TEND + 101.
      IF ( NEVD .EQ. 5 ) GO TO 32
      CALL DETECT ( 1. )
      CALL FIND
      TDA = TF
C     TDA IS COUNTER DETECTION TIME
      TCZ = TEND + 101.
      IF ( CZR .EQ. 0. ) GO TO 32
      D = SQRT ( XT * XT + YT * YT )
      DR = XT * ( VX - STX ) + YT * ( VY - STY )
      CALL CZDET
      TCZ = TF
   32 CALL ELIST
      KTEMP = 1
      IF ( IOPT .EQ. 5 ) RETURN
C     WRITE INITIAL SITUATION
  498 CONTINUE
      CAT = DEG ( CA )
```

```
      CTT = DEG ( CT )
      WRITE ( 6, 754 ) CAT, V, CTT, ST
      WRITE ( 6, 757 ) XT, YT
      WRITE ( 6, 764 ) D
      NSPACE = NSPACE + 1
      RETURN
```

INOUT5

```
C     END OF TRIAL
      ENTRY INOUT5
  500 NREP = NREP + 1
      PTRIAL ( NREP ) = PRD
      PDTRA ( NREP ) = PTMX
      PDSTA ( NREP ) = PSMX
      PSERCH ( NREP  ) = PDS
      NCDS ( NREP  ) = NCDST
      PTRANS ( NREP  ) = PDT
      NDET ( NREP  ) = NTE
      PMAX ( NREP  ) = PDMAX
      NCDT ( NREP  ) = NCDTR
      PTEND ( NREP ) = PT
      IF ( NSSW .EQ. 0 ) NDTRA = NDTRA + 1
      IF ( NSSW .EQ. 1 ) NDSTA = NDSTA + 1
      IF ( NEVADE .EQ. 1 ) NEDET = NEDET + 1
      IF ( IOPT .GE. 4 ) GO TO 512
      WRITE ( 6, 758 )NREP
      WRITE ( 6, 782 ) PRD
      IF ( NTOT .EQ. 0 ) GO TO  513
      WRITE ( 6, 762 )
      WRITE ( 6, 765 ) ( PTTIME ( INT), INT = 1, NTOT )
      WRITE ( 6, 767 )
      WRITE ( 6, 765 ) ( PRDET  ( INT), INT = 1, NTOT )
      WRITE ( 6,768 )
      WRITE ( 6, 765 ) ( PSTIME ( INT), INT = 1, NTOT )
      GO TO 514
  513 CONTINUE
      WRITE ( 6, 750 )
  514 CONTINUE
      NSPACE = NSPACE + 1
      WRITE ( 6, 765 ) NCYCR
  512 IF (NREP - 1) 509, 510, 509
C     TEST FOR OUTPUT OPTION
  510 GO TO ( 509, 511, 509, 511, 509 ), IOPT
C     DELETE DETAILED HISTORY FOR SUBSEQUENT TRIALS
  511 CONTINUE
      IF ( IOPT .EQ.2 .OR. IOPT .EQ. 4 ) IOPT = IOPT + 1
  509 IRUN = 2
```

```
      IF ( NREP .LT. NTRIAL ) RETURN
C     GAME COMPLETE.  IRUN = 10
  501 IRUN = 3
      RETURN
                                        INOUT6
C     END OF EVENT
      ENTRY INOUT6
  300 IRUN = 1
      GO TO ( 530, 530, 508, 530, 508 ), IOPT
  530  IF ( DR .GT. 0. ) GO TO 532
      WRITE ( 6, 774  ) TCUR
      GO TO 533
  532 WRITE ( 6, 751  ) TCUR, TD
C     WRITE EVENT DETAILS
  533 WRITE ( 6, 781  ) PD
      WRITE ( 6, 782  ) PRD
C     WRITE INTELLIGENCE DATA
  525 IF ( NEWINT ) 516, 516, 515
  515 WRITE ( 6, 791  )
      CTEMP = DEG ( CTINT )
      WRITE ( 6, 761  ) XTE, YTE, CTEMP, STINT
C     WRITE ATTACKER SEARCH MODE
  516 IF ( SSW ) 503, 503, 504
  503 WRITE (6, 752)
      GO TO 505
  504 WRITE (6, 753)
C     WRITE UNIT COURSE, SPEED, POSITION AND RANGE
  505 CAT= DEG ( CA)
      CTT = DEG ( CT  )
      WRITE ( 6, 754  ) CAT, V, CTT, ST
      WRITE ( 6, 757  ) XT, YT
      WRITE ( 6, 763  ) XA, YA
      WRITE ( 6, 764  ) D
C     TEST FOR NEW PAGE
      NSPACE = NSPACE + 1
      IF ( NSPACE .LT. 5 ) RETURN
      WRITE ( 6, 700  ) NUMBER, NTEMP, KDATA
      KDATA = KDATA + 1
  531 NSPACE = 0
      RETURN
                                        INOUT7
C     END OF GAME SUMMARY
      ENTRY INOUT7
  507 IF ( NSPACE ) 502, 502, 517
```

```
517 CONTINUE
    WRITE ( 6, 700 ) NUMBER, NREP, KDATA
    KDATA = KDATA + 1
502 WRITE ( 6, 755 ) NREP
    WRITE ( 6,777 ) NUMBER
    WRITE ( 6, 795 )  RSTART
    WRITE ( 6, 796 ) TBEST, XBEST, YBEST
    NTEMP = NREP
    IF ( NEVD .EQ. 5 ) GO TO 506
    WRITE ( 6, 787 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6, 797 ) ( NCDT ( INT ), INT = 1, NREP )
    IF ( NREP .GT.1 ) CALL STAT ( 2, DELTWO, NCDT,NREP,XBAR,VAR, 0 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
    WRITE ( 6, 788 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6, 797 ) ( NCDS ( INT ), INT = 1, NREP )
    IF ( NREP .GT.1 ) CALL STAT ( 2, DELTWO, NCDS,NREP,XBAR,VAR, 0 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
    WRITE ( 6, 790 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6, 797 ) ( NDET ( INT ), INT = 1, NREP )
    IF ( NREP .GT.1 ) CALL STAT ( 2, DELTWO, NDET,NREP,XBAR,VAR,0 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
506 WRITE ( 6, 785 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6,  779 ) ( PTEND ( INT ) , INT = 1, NREP )
    IF ( NREP .GT.1 ) CALL STAT ( 1, PTEND , NCDT,NREP,XBAR,VAR, 1 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
    NREP = NTEMP
    WRITE ( 6, 792 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6, 779 ) ( PTRIAL ( INT ) , INT = 1, NREP )
    IF ( NREP .GT. 1 ) CALL STAT ( 1, PTRIAL, NCDT,NREP,XBAR,VAR,0 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
    WRITE ( 6, 793 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6, 779 ) ( PTRANS ( INT ) , INT = 1, NREP )
    IF ( NREP .GT. 1 ) CALL STAT ( 1, PTRANS, NCDT,NREP,XBAR,VAR,0 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
    WRITE ( 6, 794 )
    IF ( NSUP .EQ. 0 )
   2WRITE ( 6, 779 ) ( PSERCH ( INT ) , INT = 1, NREP )
    IF ( NREP .GT. 1 ) CALL STAT ( 1, PSERCH, NCDT,NREP,XBAR,VAR,0 )
    IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
    WRITE ( 6, 700 ) NUMBER, NREP, KDATA
    KDATA = KDATA + 1
    WRITE ( 6, 775 )
```

```
      WRITE ( 6, 771 )
      WRITE ( 6, 760 ) NDTRA, NDSTA, NEDET
      WRITE ( 6, 784 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( PMAX  ( INT ) , INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, PMAX  , NCDT,NREP,XBAR,VAR, 0 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      WRITE ( 6, 785 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( PDSTA (INT ) , INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, PDSTA , NCDT,NREP,XBAR,VAR, 0 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      WRITE ( 6, 783 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( PDTRA (INT ) , INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, PDTRA , NCDT,NREP,XBAR,VAR, 0 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      WRITE ( 6, 776 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( TDET (INT), INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, TDET  , NCDT,NREP,XBAR,VAR, 1 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      IF ( NREP .GT. 1 ) WRITE ( 6, 798 ) NREP
      NREP = NTEMP
      WRITE ( 6, 775 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) (  TORD  (INT), INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, TORD  , NCDT,NREP,XBAR,VAR, 1 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      IF ( NREP .GT. 1 ) WRITE ( 6, 798 ) NREP
      NREP = NTEMP
      WRITE ( 6, 772 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) (  TCURD (INT), INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, TCURD , NCDT,NREP,XBAR,VAR, 1 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      IF ( NREP .GT. 1 ) WRITE ( 6, 798 ) NREP
      NREP = NTEMP
      WRITE ( 6, 773 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( DELONE (INT), INT = 1, NREP )
      IF ( NREP .GT.1 ) CALL STAT ( 1, DELONE, NCDT,NREP,XBAR,VAR, 1 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      IF ( NREP .GT. 1 ) WRITE ( 6, 798 ) NREP
      NREP = NTEMP
      WRITE ( 6, 756 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( DELTWO (INT), INT = 1, NREP )
```

```
      IF ( NREP .GT.1 ) CALL STAT ( 1, DELTWO, NCDT,NREP,XBAR,VAR, 1 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      IF ( NREP .GT. 1 ) WRITE ( 6, 798 ) NREP
      NREP = NTEMP
      IF ( CZR .EQ. 0. ) RETURN
      WRITE ( 6, 799 )
      IF ( NSUP .EQ. 0 )
     2WRITE ( 6, 779 ) ( CZTIME(INT ), INT = 1, NREP )
      CALL STAT (1, CZTIME, NCDT, NREP, XBAR, VAR, 1 )
      IF ( NREP .GT. 1 ) WRITE ( 6, 769 ) XBAR, VAR
      IF ( NREP .GT. 1 ) WRITE ( 6, 798 ) NREP
      NREP = NTEMP
  508 RETURN
  700 FORMAT ( '1', 18X, '   DATA SET 'I5, '    TRIAL 'I5, '    PAGE ' I5
     2    ///    )
  701 FORMAT (14I5)
  702 FORMAT (7F10.2)
  703 FORMAT ( 6F10.2   )
  704 FORMAT ( 17H  INPUT DATA SET I5 )
  705 FORMAT (/20H INTELLIGENCE TIMES )
  706 FORMAT(//9H NTRIAL = I4,8H     M = I2,8H     N = I3,11H    IOPT =
     2 I2, 11H     NOPT = I2,'    NCYCR = ' I10,/11H    NEVD = I1,
     3     13H    NCOMP =    I2, '     INRAND = ' I2, '     NC = 'I2,
     4        '      NSUP = ' I1, '     NRTT = ' I1, ' ICZ = 'I1 )
  707 FORMAT (/ 8H TEND = F6.2,11H     CINT = F5.2,10H     XTI = F7.2,
     2 10H     YTI = F7.2, 9H     TL = F4.2,/11H     TINT = F4.2,
     3 12H     ETIME = F6.2 )
  708 FORMAT (/6H SS = F5.2, 9H     SA = F5.2, 9H     TI = F5.2,
     2 10H     CAI = F6.2, 9H     SI = F5.2,/10H    AMB = F6.2 ,
     3 12H     SIGMA = F4.2 )
  709 FORMAT ( / 14H TARGET TRACKS    /
     260H     CST        SPT        TT         PINT       SPAX       SPAY
  710 FORMAT ( / 9H EVANG = F6.2, 12H     EVSPD = F6.2, 9H     SE = F5.2,
     2    9H     CE = F5.2,  10H     SAF = F4.2,/12H    GAINA = F5.2,
     3    12H    GAINT = F5.2 )
  711 FORMAT ( // 24H ATTACKER NOISE CURVES    )
  712 FORMAT ( // 24H TARGET NOISE CURVES      )
  713 FORMAT ( // 23H PROPAGATION LOSS CURVE )
  714 FORMAT ( 50H        TI        RINP       BINP       CINP       SINP   )
  715 FORMAT ( 5F10.2 )
  716 FORMAT ( //'  CZR = ' F6.2, '  CZW = ' F6.2,'  CZSE = ' F6.2,
     2        '  CZCE = ' F6.2, '  CZBE = ' F6.2, / '  CZRE = ' F6.2 )
  717 FORMAT ( 105H INTELLIGENCE TIME OPTION (NOPT) AND INTELLIGENCE CO
     2PUTATION OPTION (NCOMP) ARE INCOMPATABLE. ABORT RUN     I5 )
  718 FORMAT ( 20A4 )
  719 FORMAT ( 5 ( I5, F10.2 ))
  720 FORMAT ( // '   ENVIRONMENTAL DATA ' )
```

```
721 FORMAT ( //'  OPTION INPUTS ' )
722 FORMAT ( //'  SITUATION INPUTS ' )
750 FORMAT (//'  NO POSITIVE DETECTION PROBABILITIES ESTABLISHED '/)
751 FORMAT ( '                          CURRENT INTELLIGENCE TIME = 'F6.2 ,
   2  '                    EXPECTED CPA TIME = ' F6.2 )
752 FORMAT (44H                           ATTACKER NOT ON STATION    )
753 FORMAT (40H                           ATTACKER ON STATION  )
754 FORMAT ( 38H                           ATTACKER COURSE = F5.1,9H SPEED =
   2 F4.1, /   38H                            TARGET COURSE = F5.1, 9H SPEE
   3 =  F5.1  )
755 FORMAT(///53H                                                END OF GAME
   2     /45H                                         TOTAL OF I3,7H TRIALS
756 FORMAT (// '    DELAYS FROM BROADCAST TO MAXIMUM PROBILITIES'/)
757 FORMAT ( 39H                           TARGET COORDINATES   2F10.2 )
758 FORMAT (///'                   END OF TRIAL SUMMARY OF DETECTION PROBA
   2ILITIES - TRIAL ' I5 // )
759 FORMAT (/// 41H ATTACKER DETECTS TARGET. PROBLEM TIME =   F6.2 )
760 FORMAT (/'       TRANSIT' I5, / '          SEARCH ' I5, /
   2  '      EVASION' I5 / )
761 FORMAT ( 53H                           UPDATED INTELLIGENCE COORDINATES
   2   2F10.2, 9H  COURSE  F7.2, 7H SPEED F5.2, 4H KTS )
762 FORMAT (/'   TRANSIT PROBABILITY TIMES '/)
763 FORMAT ( 41H                           ATTACKER CORDINATES    2F10.2  )
764 FORMAT ( 27H                           RANGE =   F7.2, 6H MILES   )
765 FORMAT ( 15F8.2 )
766 FORMAT ( // ' NCYCR = ' I10 )
767 FORMAT (/'  ESTABLISHED PROBABILITIES ' /     )
768 FORMAT (/'  ON STATION PROBABILITY TIMES '/)
769 FORMAT (/'       SAMPLE MEAN = ' F8.3, '          SAMPLE VARIANCE
   2= ' F9.3 )
770 FORMAT (/// 15H COMMENCE TRIAL  I3 //  )
771 FORMAT ( '   NUMBER OF OCCURENCES OF MAXIMUMDETECTION PROBABILIT
   2 DURING: '  )
772 FORMAT (// '    ACQUISITION TIMES OF INTELLIGENCE LEADING TO MAXI
   2UM PROBABILITIES'  / )
773 FORMAT (// '    DELAYS FROM ACQUISITION TO BROADCAST ' )
774 FORMAT (    42H                          CURRENT INTEL. TIME = F6.2,/
   2  '                 RANGE OPENING')
775 FORMAT (/// ' THE FOLLOWING DATA APLIES TO THE TIME OF MAXIMUM OB
   2ERVED PROBABILITY OF DETECTION '// )
776 FORMAT (/'   TIMES OF LAST BROADCAST BEFORE MAXPROBABILITIES')
777 FORMAT ( ///    44H                                         DATA SET
   2      I5,  8H SUMMARY    /// )
778 FORMAT (// '    TIMES OF MAXIMUM DETECTION PROBABILITIES ' / )
779 FORMAT (    12F10.2 )
C
780 FORMAT ( // 20A4 )
781 FORMAT (    '                      CURRENT PROBABILITY OF DETECTIO
```

```
  2 ' F6.3 )
782 FORMAT (        '                          CUMULATIVE PROBABILITY OF DETEC
  1ION ' F 6.3   )
783 FORMAT(/'     MAXIMUM TRANSIT PROBABILITIES '   )
784 FORMAT                (/'     MAXIMUM DETECTION PROBABILITIES ' )
785 FORMAT (/'      MAXIMUM SEARCH PROBABILITIES ' )
786 FORMAT (/'     TIMES TO END TRIAL ')
787 FORMAT (/'0     COUNTERDETECTIONS OF ATTACKER BY TARGET EACH TRIAL
  2 // '                 DURING TRANSIT ')
788 FORMAT ( /      '                 DURING SEARCH '/)
789 FORMAT ( '             MEAN ESTIMATE = 'F10.4, '       ESTIMATED VARI
  2ANCE = ' F10.4         )
790 FORMAT ( /    '                       TOTAL '/)
791 FORMAT ( '                              ATTACKER RECEIVES LATEST INTELLIGEN
  2E  '  )
792 FORMAT ( // '       CUMULATIVE PROBABILITIES EACH TRIAL ' )
793 FORMAT ( // '       CUMULATIVE TRANSIT PROBABILITIES EACH TRIAL' )
794 FORMAT ( // '       CUMULATIVE STATION PROBABILITIES EACH TRIAL ' )
795 FORMAT ( //   '        INITIAL RANGE TO TARGET ' F8.2, ' MILES ' )
796 FORMAT ( // '         OPTIMAL TARGET INTERCEPT UNDER PERFECT INFORMA
  2ION '//'               TIME'F6.2, '    POSIT' 2F9.2 )
797 FORMAT (    12I10 )
798 FORMAT ( / '  TOTAL POSITIVE ENTRIES ' I4 )
799 FORMAT ( // '  CONVERGENCE ZONE DETECTION TIMES ' )
    END
```

UPDATE

```
      SUBROUTINE UPDATE
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMS, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / UPD / OT, PD ,DR, D, NOCZ, INCZ
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / SPEC2 / PT, ICOUNT
C     UPDATE UNIT POSITIONS
  312 XA = XA + VX * ( PT - OT )
      YA = YA + VY * ( PT - OT )
      XT = XT + STX * ( PT - OT )
      YT = YT + STY * ( PT - OT )
      OT = PT
      D = SQRT (( XT - XA ) ** 2 + ( YT - YA ) ** 2 )
  100 CALL DETECT ( 0. )
      PD = PDET ( D )
      DR = ( XT - XA ) * ( VX - STX ) + ( YT - YA ) * ( VY - STY )
      INCZ = 1
      IF (( D .GT. CZR - CZW ).AND. ( D .LT. CZR + CZW )) RETURN
      INCZ = 0
      NOCZ = 0
      RETURN
      END
```

FIND

```
      SUBROUTINE FIND
C     COMPUTE DETECTION TIME BASED ON RELATIVE VECTOR, CURRENT POSITION
C     AND DETECTION RANGE
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / SPEC1 / R, V, ST, PROP, TF
C     COMPUTE RELATIVE SPEED AND RANGE COMPONENTS
      XD = XT - XA
      YD = YT - YA
      TF = 0.
C     TEST FOR RANGE WITHIN DETECTION RANGE
      IF  ( XD*XD + YD*YD  .LT. R*R ) RETURN
```

```
      VXR =  VX - STX
      VYR = VY - STY
      TF = 1000.
      IF ( XD * VXR + YD * VYR .LE. 0. ) RETURN
      IF (( ABS( VXR) .GT. .001 ) .AND. ( ABS ( VYR) .GT. .001 ))
     2     GO TO 102
      IF ( ABS ( VYR ) .GT. .001 ) TF = YD / VYR
      IF ( ABS ( VXR ) .GT. .001 ) TF = XD/ VXR
      IF ( TF .LT. 0. ) TF = 0.
      CPAX = XA - TF * VX
      CPAY = YA - TF * VY
      GO TO 101
C     COMPUTE CPA
  102 CONTINUE
      A = VYR / VXR
      B = 1. / A
      CPAX = ( A * XD - YD )/( A + B )
      CPAY = -B * CPAX
  101 CONTINUE
      CPASQ = CPAX ** 2 + CPAY ** 2
C     TEST FOR CPA WITHIN DETECTION RANGE
      TF = 1000
      IF ( R*R .LE. CPASQ ) RETURN
C     COMPUTE TIME UNITS WILL BE AT DETECTION RANGE
  103 RCPA = SQRT ( R * R - CPASQ )
      DRANGE = SQRT ( XD ** 2 + YD ** 2) - RCPA
      VR = SQRT ( VXR * VXR + VYR * VYR )
      TF = DRANGE / VR
      RETURN
      END
```

CPAT

```
      SUBROUTINE CPAT
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / SPEC1 / R, V, ST, PROP, TF
      VXR = STX - VX
      VYR = STY - VY
      XD = XT - XA
      YD = YT - YA
      TF = 0.
      IF ( XD * VXR + YD * VYR .GE. 0. ) RETURN
      IF (( ABS ( VXR ) .LE. .001 ) .AND.( ABS ( VYR ) .LE. .001))RETUR
      IF (( ABS (VXR ) .LE. .001 ) .OR. ( ABS ( VYR ) .LE. .001 ))
```

```
     2     GO TO 10
      A = VXR / VYR
      B = 1. / A
      X = ( B * XD - YD ) / ( A + B )
      TF = ( X - XD ) / VXR
      RETURN
   10 IF ( ABS ( VXR ) .LE. .001 ) GO TO 20
      TF = -XD / VXR
      RETURN
   20 CONTINUE
      TF = -YD / VYR
      RETURN
      END
```

DETECT

```
      SUBROUTINE DETECT ( CDET )
C     COMPUTE DETECTION RANGE
      COMMON / INP1 / NTRIAL, M, N, IOPT, NOPT, NCYCR, NEVD,
     2                NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INP4 / VN(7), SNA(7), RNA(7), STN(7), SNT(7),
     2                RNT(7), PLOS(7), RDET(7)
      COMMON / SPEC1 / R, V, ST, PROP, TF
      IF ( CDET ) 1, 1, 7
C     TARGET DETECT ATTACKER
    7 GAIN = GAINT
      CALL CURVE ( 7, STN, SNT, ST, SELF, ERROR )
C     COMPUTE ATTACKER NOISE
    8 CALL CURVE ( 7, VN, RNA, V, RAD, ERROR )
      GO TO 3
C     ATTACKER DETECT TARGET
    1 GAIN = GAINA
      CALL CURVE ( 7, VN, SNA, V, SELF, ERROR )
      IRET = 2
      IF ( ERROR ) 2, 2, 100
C     COMPUTE TARGET NOISE
    2 CALL CURVE ( 7, STN, RNT, ST, RAD, ERROR )
      IRET = 3
      IF ( ERROR ) 3, 3, 100
C     SELECT AMBIENT NOISE FACTOR
    3 IF ( SELF .LT. AMB ) SELF = AMB
```

```
    5 PROP = RAD - SELF + GAIN
      IF ( CDET .LE. 0. ) RETURN
C     ENTER PRCPAGATION LOSS CURVE TO DETERMINE DETECTION RANGE
      CALL CURVE ( 7, PLOS, RDET, PRCP, R, ERROR )
      IRET = 4
      IF ( ERROR ) 5, 6, 100
  100 GO TO ( 105, 105, 109, 105, 1C9 ), IOPT
  109 GO TO ( 6, 2, 3, 6 ), IRET
  105 WRITE ( 6, 101 )
      GO TO ( 6, 106, 107, 108 ), IRET
  106 WRITE ( 6, 102 ) V
      GC TO 2
  107 WRITE ( 6, 103 ) ST
      GO TO 3
  108 WRITE ( 6, 104 ) PRCP
      GO TO 6
  101 FORMAT ( // 57H          SONAR EQUATION PARAMETERS EXCEED INPUT L
     2MITS.   )
  102 FORMAT (      47H          DATA EXRAPCLATED FOR ATTACKER SPEED =
     2        F6.1     )
  103 FORMAT ( 46H          DATA EXTRAPCLATED FOR TARGET SPEED =  F6.1
  104 FORMAT ( 51H          DATA EXTRAPCLATED FOR PROPAGATION LOSS =
     2  F6.1 )
    6 RETURN
      END
```

CZDET

```
      SUBROUTINE CZDET
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / UPD / CT, PD ,DR, D, NOCZ, INCZ
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / SPEC1 / R, V, ST, PRCP, TF
      DATA NCZT / 0 /
C     CZDET COMPUTES THE TIME OF THE NEXT CONVERGENCE ZONE EVENT
      IF ( NCZT .GT. 0 ) GC TC 1
      R2SQ = CZR ** 2
      R3SQ = ( CZR + CZW ) ** 2
      NCZT = 1
    1 CONTINUE
      IRUN = 2
```

```
      IF ( DR .GT. 0. ) GO TO 5
C     RANGE IS OPENING
      TF = 1000.
      IF ( D .GT. CZR + CZW ) RETURN
C     RANGE IS WITHIN THE OUTER CZ RADIUS
      TF = 0.
      IF ( D .GT. CZR ) RETURN
C     RANGE IS WITHIN THE CENTRAL CZ RADIUS
      IRUN = 1
      GO TO 10
C     RANGE IS CLOSING
    5 IF ( D .GT. CZR ) GO TO 7
C      RANGE IS WITHIN CENTRAL CZ RADIUS
      TF = 0.
      IF ( D .GT. CZR - CZW ) RETURN
C     RANGE IS WITHIN INNER CZ RADIUS
      GO TO 10
    7 IRUN = 3
   10 CONTINUE
C     COMPUTE CPA POSITION
      XD = XT - XA
      YD = YT - YA
      VXR = VX - STX
      VYR = VY - STY
      IF (( ABS (VXR) .GT. .001 ) .AND.  ( ABS (VYR) .GT. .001 ))
     2     GO TO 13
      CPAX = XD
      CPAY = YD
      IF ( ABS (VXR) .GT. .001 ) CPAX = 0.
      IF ( ABS (VYR) .GT. .001 ) CPAY = 0.
      GO TO 12
   13 A = VYR / VXR
      B = 1. / A
      CPAX = (    A * XD - YD ) / ( A + B )
      CPAY = - B * CPAX
   12 CPASQ = CPAX ** 2 + CPAY ** 2
      IF ( CPASQ .GT. R2SQ ) GO TO 23
      RCZ = SORT ( R2SQ - CPASQ )
      RA = SORT ( D*D -  CPASQ )
      DIST = RCZ + RA
      IF ( IRUN .EQ. 1 ) DIST = RCZ - RA
      IF ( IRUN .EQ. 3 ) DIST = RA - RCZ
      TF = DIST / SQRT ( VXR ** 2 + VYR ** 2 )
      RETURN
   23 CONTINUE
      TF = 1000.
      IF ( CPASQ .GT. R3SQ ) RETURN
      RA = SQRT ( D*D -  CPASQ )
```

```
      TF =  RA   / SQRT ( VXR ** 2 + VYR ** 2 )
      RETURN
      END
```

PDET

```
      FUNCTION PDET ( CPA )
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INP4 / VN(7), SNA(7), RNA(7), STN(7), SNT(7),
     2                RNT(7), PLOS(7), RDET(7)
      COMMON / SPEC1 / R, V, ST, PROP, TF
      DIMENSION PROB ( 40 )
      DATA PROB / .5, .5398, .5793, .6179, .6554, .6915, .7257, .7580,
     2  .7881, .8159, .8413, .8643, .8849, .9032, .9192, .9332, .9452,
     3  .9554, .9641, .9713, .9773, .9821, .9861, .9893, .9918, .9938,
     4 .9953, .9965, .9974, .9981, .9987, .9990, .9993, .9995, .9997,
     5  .9998, .9998, .9999, .9999, 1. /
      Z = 10.
      CALL CURVE ( 7, RDET, PLOS, CPA, ELOS, ERROR )
      IF ( ERROR .GT. 0.)GO TO 10
      Z = ( ELOS - PROP ) / SIGMA
      ZTEST = 10. * ABS ( Z ) + 1
      I = ZTEST
      IF ( I .GE. 40 ) GO TO 10
      PDET = PROB (I) + ( ZTEST - FLOAT (I) ) *(PROB (I + 1) - PROB (I)
    5 IF ( Z .GT. 0.) PDET = 1. - PDET
      RETURN
   10 PDET = 1.
      GO TO 5
      END
```

AVOID

```
      SUBROUTINE AVOID ( N )
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
                      SS, SA, VI, CAI, SI, AMB, SIGMA,
                      EVANG, EVSPD, SE, CE, SAF, GAINA,
                      GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      OMMON / POSIT / XA, YA, XT, YT
```

```
      COMMON / CRSE / CA, CT
      COMMON / SPEC1 / R, V, ST, PROP, TF
      GO TO ( 1, 2, 3, 4, 9, 100 ) , N
C     EVASION OPTION ONE
    1 CT = CT + 3.1416
      ST = ST / 2.
      GO TO 9
C     EVASION OPTION TWO
    2 X = XA - XT
      Y = YA - YT
      B = COURSE ( X, Y )
      CT = B + EVANG
      GO TO 10
C     EVASION OPTION THREE
    3 X = XT - XA
      Y = YT - YA
      BR = COURSE ( X, Y )
      IF ( ABS ( BR - CA ) - 3.1416 ) 7, 6, 5
    5 IF ( BR - CA ) 8, 6, 6
    7 IF ( BR - CA ) 6, 6, 8
C     ATTACKER HAS PORT AOB. TARGET EVADE TO STARBOARD.
    6 CT = CA + EVANG + 3.1416
      GO TO 10
C     ATTACKER HAS STARBOARD AOB.  TARGET EVADE TO PORT.
    8 CT = CA - EVANG + 3.1416
      GO TO 10
C     EVASION OPTION FOUR
    4 X = XT - XA
      Y = YT - YA
      BR = COURSE ( X, Y )
      IF ( ABS ( BR - CA) - 3.1416 ) 17, 16, 15
   15 IF ( BR - CA ) 18, 16, 16
   17 IF ( BR - CA ) 16, 16, 18
C     ATTACKER HAS PORT AOB.  TARGET EVADE TO STARBOARD.
   16 CT = BR + EVANG + 3.1416
      GO TO 10
C     ATTACKER HAS STARBOARD AOB.  TARGET EVADE TO PORT.
   18 CT = BR - EVANG + 3.1416
   10 ST = ST + EVSPD
    9 RETURN
  100 CALL SPCL
      RETURN
      END
```

```
      SUBROUTINE INTEL
C     INTEL DETERMINES ESTIMATED TARGET POSITION COURSE AND SPEED AS
C    REQUIRED BY THE INTELLIGENCE OPTION
      COMMON / INP1 / NTRIAL, M, N, IOPT, NOPT, NCYCR, NEVD,
     2                NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INP3 / CST(50), SPT(50), TT(50), PINT(50),
     2                SPAX(50), SPAY(50), TI(100), RINP(100)
     3               ,BINP(100), CINP(100), SINP(100),
     4                WORDS (40)
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / CRSE / CA, CT
      COMMON / INTGRU / I, J, JJ, XORIG, YORIG, TORIG,
     2                  XDINT(100), YDINT(100), SDINT(100),
     3                  CDINT(100), TDINT (100), EVADE
      COMMON / SPEC1 / R, V, ST, PROP, TF
      COMMON / SPEC2 / PT, ICOUNT
      JJ = J - 1
      C = CST (I)
      S = SPT (I)
      IF ( NRTT .EQ. 0 .OR. EVADE .EQ. 1. ) GO TO 14
      C = DEG ( CT )
      S = ST
   14 CONTINUE
      IF ( NCOMP - 2 ) 1, 1, 2
C     RANDOM POSITION IN SPA
    1 IF (INRAND .LE. 2 ) GO TO 11
      CALL NORMAL ( NCYCR, SIG )
      XDINT ( JJ ) = ( SIG / 2. ) * SPAX ( I ) + XT
      CALL NORMAL ( NCYCR, SIG )
      YDINT (JJ  ) = ( SIG / 2. ) * SPAY ( I ) + YT
      GO TO 7
   11 XDINT (JJ) = RAND ( NCYCR ) * SPAX (I) + XT
      YDINT (JJ) = RAND ( NCYCR ) * SPAY (I) + YT
    7 IF ( NCOMP .EQ. 1 ) GO TO 3
      GO TO 5
C     INPUT POSITION
    2 CONTINUE
      B = RAD ( BINP (JJ))
      XDINT (JJ) = RINP (JJ) * SIN ( B ) + XT
```

```
      YDINT (JJ) = RINP (JJ) * COS ( B ) + YT
      IF ( NCOMP - 4 ) 3, 4, 5
C     RANDOM COURSE AND SPEED
    3 IF (( INRAND .EQ. 1 ) .OR. ( INRAND .EQ. 3 )) GO TO 13
      CALL NORMAL ( NCYCR, SIG )
      SDINT ( JJ ) = ( SIG / 2. ) *SE + S + SAF
      CALL NORMAL ( NCYCR, SIG )
      CDINT ( JJ ) = ( SIG / 2. ) *CE + RAD ( C )
      RETURN
   13 SDINT (JJ) = RAND ( NCYCR ) * SE + S + SAF
      CDINT (JJ) = RAND ( NCYCR ) * CE + RAD ( C )
      GO TO 6
C     INPUT COURSE AND SPEED
    4 CONTINUE
      C = RAD ( CINP (JJ))
      SDINT (JJ) = SINP (JJ)
      CDINT (JJ) = C
      GO TO 6
C     COMPUTED COURSE AND SPEED
    5 XDIF = XDINT (JJ) - XORIG
      YDIF = YDINT (JJ) - YORIG
      CDINT (JJ) = COURSE ( XDIF, YDIF )
      SDINT (JJ) = SQRT ( XDIF * XDIF + YDIF * YDIF ) / ( PT - TORIG )
     2             + SAF
      IF ( SDINT(JJ) .GT. S       + SAF + SE )
     2         SDINT(JJ) = S      + SAF + SE
      IF ( SDINT(JJ) .LT. S       - SE )
     2         SDINT(JJ) = S      - SE
    6 RETURN
      END
```

INTDET

```
      SUBROUTINE INTDET
      COMMON / INP1 / NTRIAL, M, N, IOPT, NOPT, NCYCR, NEVD,
     2                NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / CRSE / CA, CT
      COMMON / INTGRU / I, J, JJ, XORIG, YORIG, TORIG,
     2                   XDINT(100), YDINT(100), SDINT(100),
     3                   CDINT(100), TDINT (100), EVADE
      COMMON / SPEC1 / R, V, ST, PROP, TF
```

```
      COMMON / SPEC2 / PT, ICOUNT
C     CALCULATE AND STORE LATEST INTELLIGENCE
  410 GO TO ( 408, 414, 408, 408, 414 )  , NCOMP
C     COURSE AND SPEED ARE RANDOM OR INPUT
  408 CALL INTEL
      TDINT (JJ) = PT
      GO TO 421
C     COURSE AND SPEED ARE COMPUTED
  414 IF ( ICOUNT ) 420, 418, 417
C     FIRST DETECTION OF TRIAL
  417 CALL INTEL
      SDINT (1) = ST + SE * RAND (NCYCR) + SAF
      CDINT (1) = CT + CE * RAND (NCYCR)
      TDINT (1) = PT
      ICOUNT = 0
      XORIG = XDINT (1)
      YCRIG = YDINT(1)
      TCRIG = TDINT (1)
      GO TO 421
C     TARGET COURSE CHANGE ROUTINE
  420 JJ = JJ - 1
      XCRIG = XDINT (JJ)
      YORIG = YDINT (JJ)
      TORIG = TDINT (JJ)
      JJ = JJ + 1
      ICOUNT = ICCUNT + 1
C     ROUTINE INTEL DETECTION ( COMPUTED )
  418 CALL INTEL
      TDINT (JJ) = PT
  421 CTEMP = DEG ( CDINT (JJ))
      GO TO ( 432, 432, 300, 432, 300 ), IOPT
  432 WRITE ( 6, 776 ) XDINT (JJ), YDINT (JJ), CTEMP, SDINT (JJ)
      GO TO 300
  776 FORMAT (   45H                    INTELLIGENCE DATA - POSIT 2F10.2
     2       9H  CCURSE    F7.2,    7H  SPEED    F5.2,   5H KTS.  )
  300 RETURN
      END
```

PROINT

```
      SUBROUTINE PROINT
      COMMON / INP1 / NTRIAL, M, N, IOPT, NOPT, NCYCR, NEVD,
     2                NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
```

```
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INTGRU / I, J, JJ, XORIG, YORIG, TORIG,
     2                  XDINT(100), YDINT(100), SDINT(100),
     3                  CDINT(100), TDINT (100), EVADE
      COMMON / INTCOM / TCUR, STINT, CTINT, XTE, YTE, IRUN,
     2                  TOR, NEWINT, NOINT
      COMMON / SPEC1 / R, V, ST, PROP, TF
      COMMON / SPEC2 / PT, ICOUNT
      IRUN = 2
      IF ( J .EQ. 1 )  RETURN
C     PROVIDE LATEST INTELLIGENCE TO ATTACKER
C     SELECT LATEST AVAILABLE INTELLIGENCE
  439 DO 401 L = 1, JJ
      LL = J - L
      IF ( PT .GE. TDINT ( LL ) + TL ) GO TO 402
  431 CONTINUE
C     NO INTELLIGENCE AVAILABLE
      RETURN
C     TEST FOR PREVIOUS RECEIPT OF INTELLIGENCE
  402 CONTINUE
      IRUN = 3
      IF ( TDINT ( LL ) .LE. TCUR ) RETURN
C     PREPARE LATEST INFORMATION
  403 TCUR = TDINT (LL)
      XINT = XDINT (LL)
      YINT = YDINT (LL)
      STINT = SDINT (LL)
      CTINT = CDINT (LL)
      V = SA
C     UPDATE INTELLIGENCE COORDINATES
  406 SXE = STINT * SIN ( CTINT )
      SYE = STINT * COS ( CTINT )
      XTE = XINT + ( PT - TCUR ) * SXE
      YTE = YINT + ( PT - TCUR ) * SYE
      TOR = PT
      NEWINT = 1
      IRUN = 1
      RETURN
      END
```

CZINT

```
      SUBROUTINE CZINT
C     CZINT COMPUTES THE CONVERGENCE ZONE INTELIGENCE ESTIMATE
      COMMON / INP1 / NTRIAL, M, N, IOPT, NCPT, NCYCR, NEVD,
     2                NCOMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / UPD / DT, PD ,DR, D, NOCZ, INCZ
      COMMON / POSIT / XA, YA, XT, YT
      COMMON / CRSE / CA, CT
      COMMON / SPEED / VX, VY, STX, STY
      COMMON / INTCOM / TCUR, STINT, CTINT, XTE, YTE, IRUN,
     2                   TOR, NEWINT, NOINT
      COMMON / SPEC1 / R, V, ST, PROP, TF
      XD = XT - XA
      YD = YT - YA
      BRG = COURSE ( XD, YD ) + RAND   ( NCYCR ) * RAD ( CZBE )
      RANGE = D + RAND ( NCYCR ) * CZRE
      XTE = XA + COS ( BRG ) * RANGE
      YTE = YA + SIN ( BRG ) * RANGE
      STINT = ST + RAND ( NCYCR ) * CZSE
      CTINT = CT + RAND ( NCYCR ) * RAD ( CZCE )
      NEWINT = 1
      RETURN
      END
```

ELIST

```
      SUBROUTINE ELIST
C     ELIST COMPILES THE INITIAL EVENT LIST
      COMMON / INP1 / NTRIAL, M, N, IOPT, NCPT, NCYCR, NEVD,
     2                NCCMP, INRAND, NC, NSUP, NRTT, ICZ
      COMMON / INP2 / TEND, CINT, XTI, YTI, TL, TINT, ETIME,
     2                SS, SA, VI, CAI, SI, AMB, SIGMA,
     3                EVANG, EVSPD, SE, CE, SAF, GAINA,
     4                GAINT, CZR, CZW, CZSE, CZCE, CZBE, CZRE
      COMMON / INP3 / CST(50), SPT(50), TT(50), PINT(50),
     2                SPAX(50), SPAY(50), TI(100), RINP(100)
     3               ,BINP(100), CINP(100), SINP(100),
```

```
     4                      WORDS (40)
      COMMON / LIST /       NTYPE(160), TE(160), K, KTEMP, TD,
     2                      TDA, TA, MI, TCZ
      K = 1
C     TARGET LEG TIMES
      DO 1 IJ= 1, MI
      TE (K) = TT (IJ)
      NTYPE (K) = 1
    1 K = K + 1
C     INTELLIGENCE TIMES
      DO 2 JI= 1, N
      TE (K) = TI (JI)
      NTYPE (K) = 2
    2 K = K + 1
C     COMMUNICATION TIMES
    3 TE (K) = CINT
      IF ( CINT .EQ. 0.)TE (K) = TEND + 100.
      NTYPE (K) = 6
      K = K + 1
C     DETECTION TIME
    4 TE (K) = TD
      NTYPE (K) = 3
      K = K + 1
C     COUNTERDETECTION TIME
      TE (K) = TDA
      NTYPE (K) = 4
      K = K + 1
C     ATTACKER STATION LEG TIME
      TE (K) = TA
      NTYPE (K) = 5
      K = K + 1
C     END OF TRIAL TIME
      TE (K) = TEND + 100.
      NTYPE (K) = 7
      K = K + 1
C     CONVERGENCE ZONE DETECTION TIME
      TE (K) = TCZ
      NTYPE (K) = 8
C     ORDER THE EVENT LIST
      CALL ORDER ( TE, NTYPE, 1, K )
      RETURN
      END
```

RPLACE

```
      SUBROUTINE RPLACE  (NT, TIME )
C     RPLACE SUBSTITUTES THE NEW VALUE FOR A ONE TIME EVENT IN THE EVEN
C     LIST FOR THE ORIGINAL VALUE. N IS THE TYPE OF EVENT. T IS THE NEW
C     TIME.
      COMMON / LIST / NTYPE(160), TE(160), K, KTEMP, TD,
     2                TDA, TA, MI, TCZ
C
      DO 1 IJ= KTEMP, K
      IF ( NTYPE (IJ)- NT) 1, 2, 1
    2 TE (IJ)= TIME
      GO TO 3
    1 CONTINUE
      RETURN
    3 CALL ORDER3 ( TE, NTYPE, IJ, K )
      RETURN
      END
```

STAT

```
      SUBROUTINE STAT ( K, A, I, N, XBAR,VAR, NO )
C     K DEFINES THE TYPE VARIABLE.  K = 0 SPECIFIES AN INTEGER ARRAY
C    A IS A ONE BY N REAL ARRAY
C     I IS A ONE BY N INTEGER ARRAY
C     XBAR IS THE SAMPLE MEAN
C     VAR IS THE SAMPLE VARIANCE
C     NO SUPRESSES ZEROS.   NO = 0 - KEEP ZEROS IN ARRAY
      DIMENSION A ( 100 ) , I ( 100 )
      SUM = 0.
      SUMSQ = 0.
      M = N
      IF ( K .EQ. 1 ) GO TO 10
      DO  5 J = 1, N
      IF (( NO .EQ. 1 ) .AND. ( I(J) .LE. 0 )) M = M - 1
      SUM = SUM + I (J)
    5 SUMSQ = SUMSQ +  I (J) * I (J)
      GO TO 15
   10 DO 12 J = 1, N
      IF (( NO .EQ. 1 ) .AND. ( A(J).LT. .0001 )) M = M - 1
      SUM = SUM + A (J)
   12 SUMSQ = SUMSQ + A (J) * A (J)
```

```
15 F = M
   XBAR = 0.
   VAR = 0.
   IF ( NO .EQ. 1 ) N = M
   IF ( M .LT. 2 ) RETURN
   XBAR = SUM / F
   VAR =  ( SUMSQ - SUM * XBAR ) / ( F - 1. )
   RETURN
   END
```

CURVE

```
      SUBROUTINE CURVE ( N, X, Y, X1, Y1, ERROR )
C CURVE MAKES A LINEAR INTERPOLATION BETWEEN DATA POINTS OF THE ARRAY
C  ( X,Y ). ERROR = 1 IF X1 IS GREATER THAN X (N)
      DIMENSION X ( 7  ), Y ( 7  )
      DO 10 I = 1, N
      IF ( X1 - X (I) ) 1, 2, 3
    1 IF ( I-1 ) 4, 5, 4
C     X1 IS SMALLER THAN X (1). ASSUME X (0) = 0, Y (0) = 0 AND CONTINU
    5 YO = 0.
      XO = 0.
      GO TO 4
    3 YO = Y (I)
      XO = X (I)
   10 ERROR = 1.
C     X1 IS GREATER THAN X(N). EXTRAPOLATE DATA LINEARLY BASED ON LAST
C     TWO DATA POINTS
      J = N - 1
      Y1 = (.X1 - X (N)) * ( Y (N) - Y (J)) / ( X (N) - X (J)) + Y (N)
      GO TO 6
C     COMPUTE Y1 NORMALLY
    4 Y1 = ( X1 - XO ) * ( Y (I) - YO ) /(X (I) - XO ) + YO
      ERROR = 0.
      GO TO 6
    2 Y1 = Y (I)
      ERROR = 0.
    6 RETURN
      END
```

ORDER

```
      SUBROUTINE ORDER ( X, L, M, N )
C     ORDER ARRANGES ARRAY X IN ASCENDING ORDER AND RETAINS THE
C     CORRESPONDING VALUE OF L
      DIMENSION X ( 160 ), L ( 160 )
      DO 1 I = M, N
      K = I
      DO 1 J = K, N
      IF ( X (I) - X (J) ) 1, 1, 2
    2 TEMP = X (I)
      X (I) = X (J)
      X (J) = TEMP
      NTEMP = L (I)
      L (I) = L (J)
      L (J) = NTEMP
    1 CONTINUE
      RETURN
```

ORDER2

```
      ENTRY ORDER2 ( X, L, M, N )
      TEMP = X(M)
      NTEMP = L (M)
      K = M + 1
      DO 3 I = K, N
      J = I - 1
      IF ( TEMP .LT. X (I) ) GO TO 4
      X (J) = X (I)
      L (J) = L (I)
    3 CONTINUE
      J = N
    4 X (J) = TEMP
      L (J) = NTEMP
      RETURN
```

ORDER3

```
      ENTRY ORDER3 ( X, L, M, N )
      IF ( M .GE. N ) GO TO 6
    5 CONTINUE
      IF ( M .GE. N ) RETURN
      IF ( X (M) .LE. X (M+1)) GO TO 6
      TEMP = X (M)
      X (M) = X (M+ 1)
```

```
      NTEMP = L (M)
      L (M) = L (M + 1)
      M = M + 1
      L (M) = NTEMP
      X(M) = TEMP
      GO TO 5
    6 CONTINUE
      IF ( M .EQ. 1 ) RETURN
      IF ( X(M) .GE. X (M - 1)) RETURN
      TEMP = X (M)
      NTEMP = L (M)
      L (M) = L (M - 1)
      X (M) = X (M - 1)
      M = M - 1
      L (M) =  NTEMP
      X (M) = TEMP
      GO TO 6
      END
```

PIM

```
      SUBROUTINE PIM ( X1, Y1, X2, Y2, V, SP, CP, X3, Y3, C, T, ERROR)
C     PIM COMPUTES COURSE C, TIME T AND POSIT  (X3, Y3) FOR A UNIT TO G
C     FROM POINT (X1, Y1) AT A VELOCITY V TO INTERCEPT PIM.  PIM INITIA
C     POSIT IS (X2, Y2), ON COURSE  CP AT SPEED SP. ERROR IS SET TO ONE
C     IF AN INTERCEPTION IS IMPOSSIBLE DUE TO SPEED DIFFERENTIAL.
      ERROR = 0.
      XD = X2 - X1
      YD = Y2 - Y1
      SX = SP * SIN ( CP )
      SY = SP * COS ( CP )
      IF ( SP - V ) 1, 2, 1
    1 IF (( SX * XD + SY * YD ) ** 2 - ( SP * SP - V * V )
     2     * ( XD * XD + YD * YD )) 50, 3, 3
    2 T = - ( XD * XD + YD * YD ) / ( 2. * ( SX * XD + SY * YD ))
      GO TO 4
    3 T = ( - ( SX * XD + SY * YD ) - SQRT (( SX * XD + SY * YD ) ** 2
     2     - ( SP * SP - V * V ) * ( XD * XD + YD * YD ))) /
     3       ( SP * SP - V * V )
    4 IF ( T ) 50, 6, 5
    5 X3 = X2 + SX * T
      Y3 = Y2 + SY * T
      A = X3 - X1
      B = Y3 - Y1
      C = COURSE ( A, B )
```

```
      GO TO 6
   50 ERROR = 1.
      T = 0.
    6 RETURN
      END
```

RAD

```
      FUNCTION RAD ( X )
C     CONVERT DEGREES TO RADIANS
      RAD = X * 3.1416 / 180.
      RETURN
      END
```

DEG

```
      FUNCTION DEG ( X )
C     CONVERT RADIANS TO DEGREES
      DEG = X * 180. / 3.1416
   75 IF ( DEG - 360.) 77, 77, 76
   76 DEG = DEG - 360.
      GO TO 75
   77 IF ( DEG ) 78, 79, 79
   78 DEG = 360. + DEG
      GO TO 77
   79 RETURN
      END
```

COURSE

```
      FUNCTION COURSE ( X, Y )
C     DETERMINES COURSE BASED ON VECTOR COMPONENTS
      IF ( Y ) 1, 2, 3
    1 COURSE = ATAN ( X / Y ) + 3.1416
      GO TO 4
    2 Y = .0001
    3 COURSE = ATAN ( X / Y )
    4 RETURN
      END
```

RNG

```
      FUNCTION RNG ( IX )
C     RANDOM NUMBER GENERATOR FOR 360-91. ( FORTRAN IV )
      IY = IX * 65539
      IF (IY) 5,6,6
    5 IY = IY + 2147483647 + 1
    6 RNG = IY
      RNG = RNG * .4656613E - 9
   50 IX = IY
      RETURN
      END
```

REVENT

```
      SUBROUTINE REVENT ( P, M, TP, TINTVL, TMAX, NCYC, TEVENT, N ,
     2                    NCYCR )
C     REVENT RANDOMLY SELECTS TIMES FOR AN EVENT, TEVENT (J), BASED ON
C     THE PROBABILITY, P (I), THAT THE EVENT WILL OCCUR IN THE TIME
C     INTERVAL, TINTVL.  P (I) IS INCREMENTED AT TIMES TP (I).
C     P (I) IS THE PROBABILITY OF AN EVENT OCCURING DURING A GIVEN TIME
C           INTERVAL.
C     M IS THE NUMBER OF PROBABILITIES TO BE COSIDERED.
C     TP (I) ARE THE TIMES AT WHICH P (I) IS REPLACED WITH P (I + 1).
C            TP (M) MUST BE GREATER THAN TMAX.
C     TINTVL  IS THE TIME INTERVAL BEING TESTED.
C     TMAX IS THE LIMMITING TIME TO BE CONSIDERED.
C     NCYC IS THE NUMBER OF TIMES TO CYCLE THE ROUTINE EACH TIME THE
C          PROBABILITY IS INCREMENTED BEFORE AN EVENT IS SCHEDULED,
C     TEVENT (J) ARE THE EVENT TIMES SELECTED.
C     N IS THE NUMBER OF EVENTS SELECTED.
      DIMENSION P (100), TP (100), TEVENT (1000)
      NREP = NCYC
      T = 0.
      K = 0
      J = 0
      DO 25 I = 1, M
    1 T = T + TINTVL
      IF ( T .GT. TMAX ) GO TO 2
    3 IF ( T - TP (I)) 4, 4, 25
    4 R = RNG ( NCYCR )
```

```
      IF ( R - P (I)) 6, 6, 1
    6 NREP = NREP - 1
      IF ( NREP .GT. 0 ) GO TO 1
      J = J + 1
    7 TEVENT (J) = T - R * TINTVL / P (I)
      GO TO 1
    2 N = J
      IF ( N .GE. 1 ) GO TO 25
      N = 1
      TEVENT ( 1)   = T
   25 NREP = NCYC
   10 RETURN
      END
```

NORMAL

```
      SUBROUTINE NORMAL ( N, X )
C     NORMAL SELECTS A RANDOM DEVIATE FROM A NORMAL ( MEAN 0, VARIANCE
C     DISTRIBUTION. TRUNCATED AT 6 STANDARD DEVIATIONS.
      X = -6.
      DO 10 I = 1, 12
      X = X +  RNG(N)
   10 CONTINUE
      RETURN
      END
```

RAND

```
      FUNCTION RAND ( NCYCR )
C     RAND SELECTS A RANDOM NUMBER FROM A UNIFORM DISTRIBUTION FROM
C     +1 TO -1.
      X = RNG ( NCYCR )
      RAND = 2. * ( X - .5 )
      RETURN
      END
```

SPCL

```
SUBROUTINE SPCL
RETURN
END
```

LIST OF REFERENCES

1. Deleted

2. Deleted

3. Williams, J. D., The Compleat Strategyst, McGraw-Hill 1954, Chapter 2.

4. Gass, Saul I., Linear Programming: Methods and Applications, Third Edition, McGraw-Hill, 1969.