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User Guide and Specification for Discrete-event Minehunting Simulation Model MHUNT

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User Guide and Specification for Discrete-Event Minehunting Simulation Model MHUNT

R.B. Watson, P.J. Ryan and B. Gilmartin

Maritime Operations Division
Aeronautical and Maritime Research Laboratory

DSTO-TN-0003

ABSTRACT

Minehunting is a complex process involving detection and classification of contacts using sonar and the subsequent identification and disposal of mines, generally using a remotely operated underwater vehicle (ROV). However, making suitable assumptions, minehunting can be approximated by a series of connected events and thus made amenable to modelling using the technique of discrete-event simulation. In this report, a discrete-event minehunting simulation model is described together with instructions for its operation. The model can be applied to evaluate the effectiveness of minehunting systems for a given operational scenario and also to investigate new concepts.

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1. Introduction

Modelling and simulation can be applied both to predict the behaviour of existing mine warfare systems in operational scenarios (and thus assist tactical decision making) and also to investigate new mine countermeasure (MCM) and mining concepts. Because of the expense and difficulties involved in conducting trials, this is frequently a useful method for studying mine warfare systems under a variety of conditions.

The Royal Australian Navy (RAN) is establishing a dedicated Mine Warfare Systems Centre (MWSC) to provide the prime focus for all operational aspects of RAN mine warfare activities [1]. Modelling and simulation will form an integral part of the MWSC's decision support systems required to enable optimum use of limited MCM assets. A hierarchy of models is required ranging across four levels:

(1) Level 1: Single vessel against a single mine

(2) Level 2: Single vessel against many mines (minehunting, minesweeping)

(3) Level 3: Several vessels against many mines (eg. MCM force, convoy)

(4) Level 4: Several MCM forces against several minefields

Models both for rapid response and detailed studies are required. The rapid response models will use analytical techniques whereas the detailed models will employ simulation techniques. These model variants are referred to as mode 1 and mode 2 respectively.

Level 2 simulation models for minesweeping, minehunting, and minefield planning have been developed and reported previously [2-4]. The existing documentation of the minehunting model (MHUNT) [3] covers the principles and applications of minehunting simulation. This report comprises a detailed specification of the MHUNT model and the information required to run it.

The MHUNT model has been used by Maritime Operations Division, AMRL, to evaluate the operational effectiveness of minehunting systems being considered by the RAN's Minehunter Coastal (MHC) Project [5]. It is expected that the model, or at least a modified version of it, will be incorporated into the MWSC.

2. Model Description

2.1 Model Overview

As explained in [3], for simulation purposes the minehunting procedure is reduced to a series of connected, discrete events such as mine detection and classification. The MHUNT model operates by first defining a minefield populated with a given number of mines and non-mines. The minehunter is constrained to traverse this minefield on a given set of tracks and each hunter/object encounter is evaluated using Monte Carlo techniques. If a mine is detected and also classified correctly a Remotely Operated Vehicle (ROV) is deployed to identify and dispose of the mine. For a given tactic of track spacing and runs per track the model calculates clearance level and other measures of effectiveness (MOE) defined for a minehunting system. Many replications of a minefield traversal are performed to determine average MOEs for a given scenario.

The main submodels comprising the model are illustrated in Figure 1.

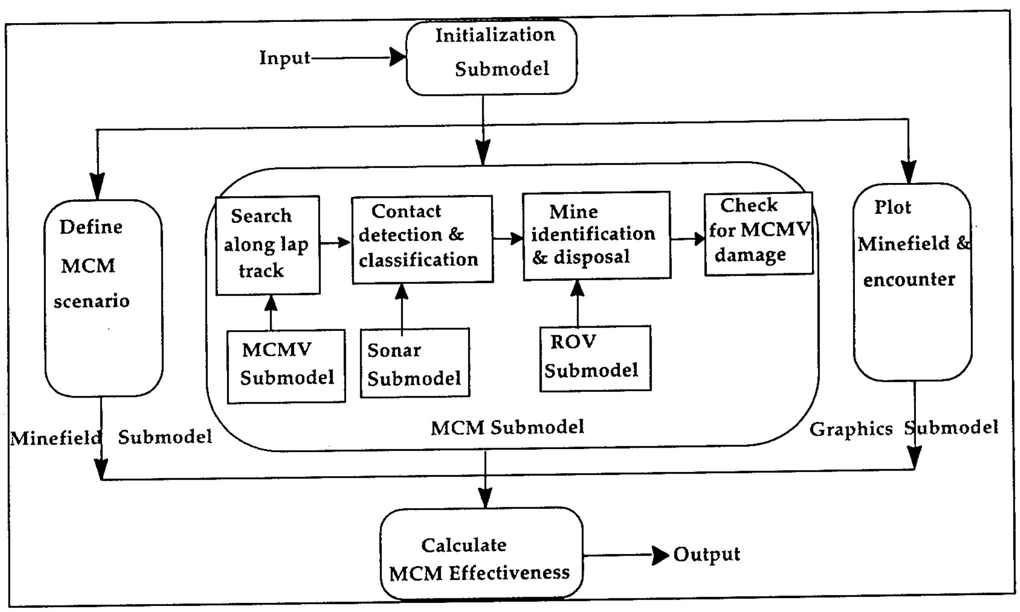


Figure 1: Submodels for minehunting model

2.1.1 Initialisation and Minefield Submodels

The Initialisation submodel receives the input data needed for a simulation run, either from the keyboard or a file stored on disk. This data includes the number of replications in each simulation run. For each replication, the Initialization Submodel calls successively the Minefield Submodel, the MCM Submodel (comprising the MCMV Submodel, Sonar Submodel, ROV Submodel and Damage Submodel) and, optionally, the Graphics Submodel. The Minefield Submodel declares the minefield to be cleared, by assigning a specified number of mines and non-mines to locations in a rectangular area.

2.1.2 MCMV Submodel

The MCMV Submodel determines the lap tracks that the MCMV will traverse, which are evenly-spaced paths parallel to the minefield axis and connected by semicircles at each end. The spacings are calculated according to the track spacing tactic included in the input data. The MCMV Submodel then simulates the movement of the MCMV along each track, and diversions off the track when contacts (mines or non-mines) are encountered.

2.1.3 Sonar, ROV and Damage Submodels

The Sonar Submodel calculates the sonar detection and classification envelopes as the MCMV moves along the track, and determines whether each contact encountered is detected and classified. Contacts detected and classified as mine are input to the ROV Submodel, which simulates the movement of the ROV to a point sufficiently near the contact to enable it to be identified. If a contact is identified as a mine, the ROV Submodel then simulates its disposal by means of a mine disposal charge (MDC). The Damage Submodel determines whether the MCMV passes within the actuation and damage radii of any mine encountered, and whether it is damaged. If the MCMV is damaged, the replication is terminated.

2.1.4 Graphics Submodel

The Graphics Submodel may be called after a single replication run, and plots the minefield and paths of the MCMV and ROV in their transit through the minefield. The results of each encounter between the MCMV and a contact are indicated on the plot.

2.2 Model Versions

The model was initially coded in FORTRAN 77 for the VAX/VMS environment. The Simpleplot graphics library was used to provide graphical output of a single minefield traversal. Random numbers required for event selection were provided either by internal VAX FORTRAN functions or NAG library functions.

The model was subsequently ported to the IBM PC MS-DOS environment for greater convenience. Various enhancements were made to improve the model's functionality. In the remainder of this report, the original VAX version of the model will be termed MHUNT Version 1 and the enhanced version MHUNT Version 2. The enhancements incorporated in MHUNT Version 2 are included in the overall model specification.

The main enhancement in MHUNT Version 2 is the adoption of a parallel process architecture. Version 1 comprised a single minehunting process, i.e. a sequence of events and states executed in a fixed order. The ROV was assumed to be continuously available, and neither those activities associated with turning it around (changing its battery, charging flat batteries, loading an MDC, etc.) nor the availability and use during MCM operations of more than one (typically two per MCMV) ROV were considered. These assumptions may fail in areas of high mine density where many ROV runs are required to identify mine-like objects. Thus it was decided to reorganise the model to allow the ROV to be modelled as a separate process running concurrently, or in parallel, to the MCMV.

Version 2 is organised into multiple parallel processes. In order to execute the events from these processes, a linked list of future events was also adopted. The model has five processes, which respectively describe the MCMV, MDC, ROV battery charger, spare ROV and next ROV to be used for mine disposal.

2.3 Model Specification

The MHUNT model was specified by means of Clymer's directed graph notation [6], a form of state transition diagram. It also incorporates Clymer's event management software for controlling its dynamic behaviour. This is a collection of Fortran subroutines, some of which have to be tailored to each application software system, while others can be incorporated unchanged. A detailed description of Clymer's methodology is provided in Annex A and short descriptions of each module are provided in Annex B. Clymer's method was adopted for the following reasons:

- Version 1 of the model had been written in Fortran with a single process and without a future events list. The model was needed urgently for the MHC Effectiveness Study [5], which meant there was insufficient time to completely redevelop the model using object-oriented design techniques. The enhancements subsequently incorporated into Version 2 were, however, judged to be essential. Clymer's directed graph notation is relatively simple and its concept of parallel, interacting processes incorporates some of the characteristics of concurrent objects which would be obtained using a proper object-oriented design.

- Clymer's book [6] is accompanied by a disk containing event management software, written in Fortran, which supports his method. No other such software was available at low cost, and for the analysts concerned (the authors) to write their own would have been both time consuming and unnecessary.

2.3.1 Directed Graph Specification of the MHUNT Model

The complete model specification is shown in Figure 2. This section describes the processes shown.

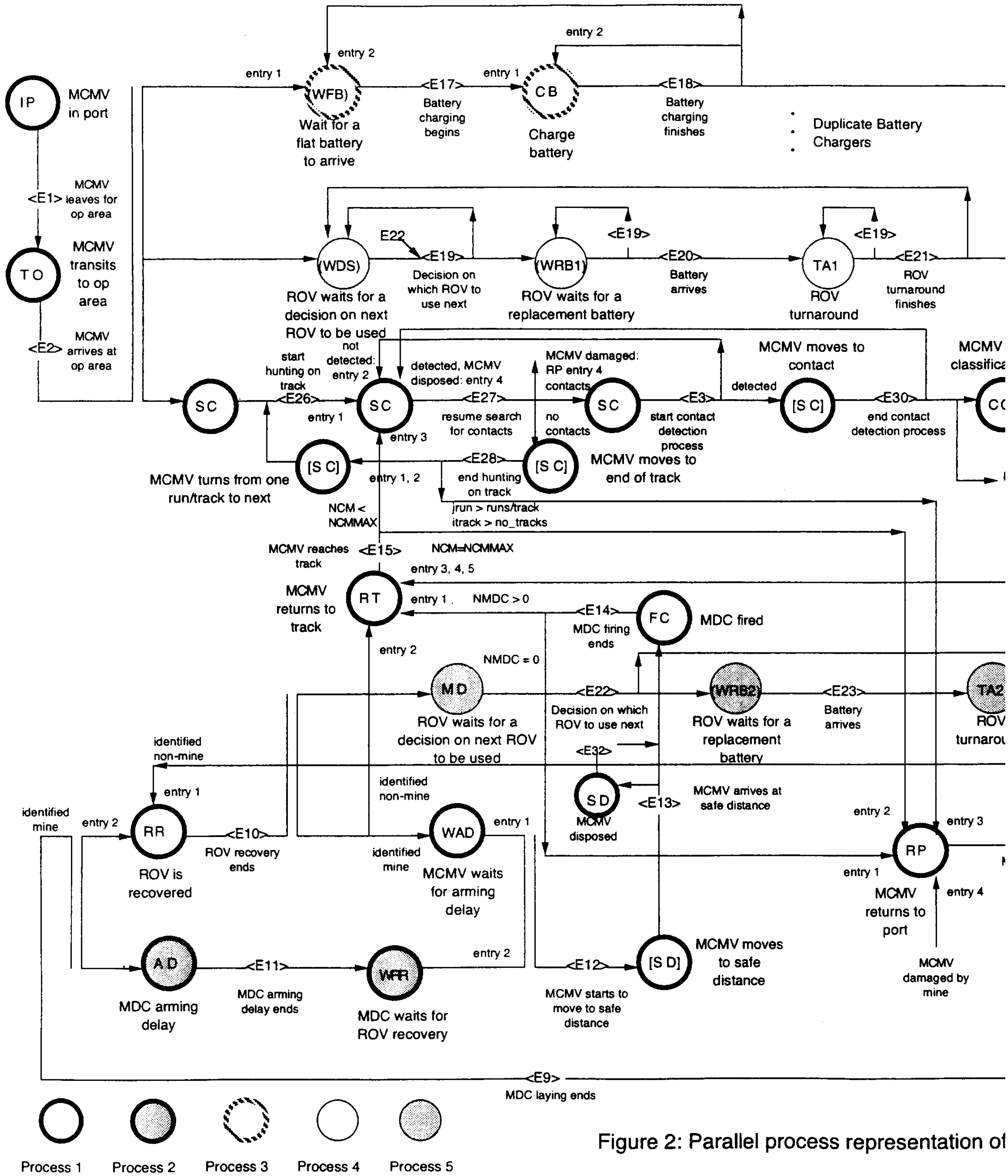
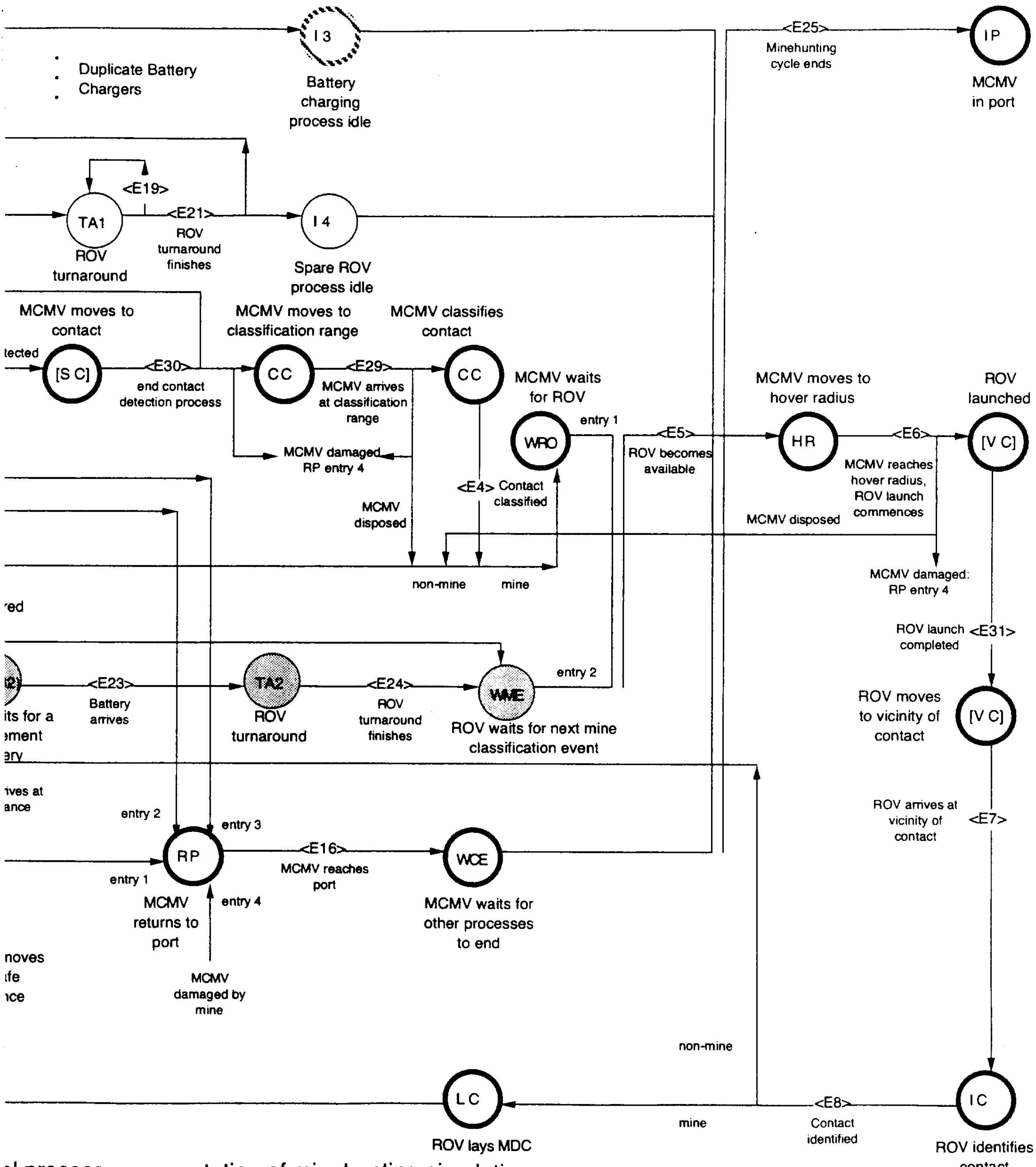


Figure 2: Parallel process representation of



el process representation of minehunting simulation

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Clymer's notation is generally used, although a minor change has been introduced: some states have been grouped into superstates, which are states at a higher level of abstraction embodying the behaviour of their substates. This change was introduced when the Version 2 model was being constructed by merging the Version 1 model with a prototype model built using Clymer's methodology: some of the states in the prototype were modelled in a simplified way, whereas the Version 1 model had developed these states in more detail, so that in the Version 2 model they became superstates. All the states in a superstate were given the same name, and are indicated as in the following example:

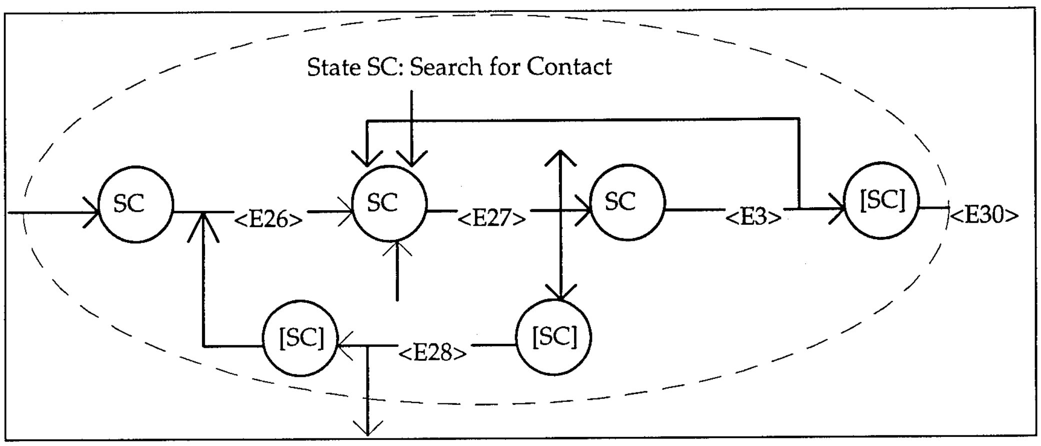

Figure 3: Superstate for search for contact process

In the above diagram, the states denoted [SC] are reaction-time states, whereas the states denoted SC are stages in the computation and do not correspond to external system behaviour (a reaction time or wait time).

There are five parallel processes depicted in Figure 2. To distinguish them on the diagram, each process has its states drawn differently as shown in the legend.

Process 1:- *MCMV/ROV Process*

This is the main process corresponding to all the states and events associated with minehunting operations i.e. excluding ROV turnaround and ROV battery charging. From event 2 (<E2> MCMV arrives at operational area) until event 5 (<E5> ROV becomes available) the MCMV is the active component, whereas from event 5 until event 10 (<E10> ROV recovery ends) the ROV is the active component. Split and assemble events control the transition from active MCMV/passive ROV to active ROV/passive MCMV. The states in process 1 are as follows:

IP	In Port
TO	Transit to Operational Area
SC	Searching for Contact
CC	Classifying Contact
WRO	Waiting for ROV
HR	Moving to Hover Radius
VC	In Vicinity of Contact
IC	Identifying Contact
LC	Laying Charge
RR	Recovering ROV
WAD	Waiting for Arming Delay
RT	Returning to Track
SD	Moving to Safe Distance
FC	Firing Charge
RP	Returning to Port
WCE	Waiting for Minehunting Cycle to End
IP	In Port

Process 2: MDC

This is a minor parallel process which represents the circumstance that event 12 (<E12>MCMV starts to move to safe distance) cannot occur until after the ROV is recovered and the MDC arming delay finishes, whichever is the longer. The states in process 2 are as follows:

AD	Waiting for Arming Delay
WRR	Waiting for ROV Recovery

Process 3: Battery Charger (#1 or #2)

This is a parallel process representing the charging of flat batteries removed from ROVs when they are recovered after operations. One or two battery chargers are allowed, and since if two are used they both follow the same process, only one process is shown in the parallel process model (Figure 2). The states in process 3 are as follows:

WFB	Waiting for Flat Battery
CB	Charging Battery
I3	Process 3 Idle

Process 4: Spare ROV

This is a parallel process representing the turnaround of one of the two ROVs. In the model, a decision as to which of the two ROVs will be used on the next ROV operation is made after an ROV is recovered from the water. The decision logic, encoded in the model, takes into account the expected battery life remaining in both ROV installed batteries and other factors. The two actual ROVs can switch between the Next ROV Process and Spare ROV Process when this decision is made. The states in process 4 are as follows:

WDS	Waiting for a Decision on Spare ROV
WRB1	Waiting for a Replacement Battery
TA1	Spare ROV in Turnaround
I4	Process 4 Idle

Process 5: *Next ROV*

This process is similar to the Spare ROV Process, but has minor differences which resulted in it being treated as a separate process. The states in process 5 are as follows:

MD	A Management Decision (on next ROV) being made
WRB2	Waiting for a Replacement Battery
TA2	Next ROV in Turnaround
WME	Waiting for next Mine Classification Event

The following are split events:

- Event 2, arrival at the operational area, as the hitherto single MCMV/ROV Process then splits into three: the Battery Charger Process, the Spare ROV Process and the ongoing MCMV/ROV process.
- Event 9, MDC laying ends, as the MCMV/ROV Process then runs in parallel to the MDC Process until either the ROV is recovered or the MDC arming delay ends, whichever is the later.
- Event 10, ROV recovery ends, as the MCMV/ROV Process then runs in parallel with the Next ROV Process until either the next ROV becomes available after turnaround or a contact is classified as a mine and hence the next ROV is required, whichever is the later.

The assemble events are:

- Event 12, MCMV starts to move to safe distance, is the assemble event for the MDC Process, i.e. it ceases to operate after event 12.
- Event 5, ROV becomes available, is the assemble event for Next ROV Process. It cannot be executed until the next ROV is available after turnaround (i.e. in the state of waiting for the next mine classification event) and a contact has been classified as a mine (i.e. the MCMV is in the state of waiting for the ROV to become available).
- Event 25, minehunting cycle ends, is the assemble event for all three then active processes. It cannot be executed until the battery charger(s) have finished charging all flat batteries, the spare ROV has finished its turnaround, and the MCMV has reached port and is in the state of waiting for the other processes to finish.

Flow charts of the key events in the MHUNT model are given at Annex C.

2.4 Other Model Enhancements

Further enhancements were made to the model. These are described in the following subsections.

2.4.1 Sonar Performance

The initial model used rectangular parameters for detection of contacts. If a contact was within a sector defined by the sonar range and detection width it had a constant probability of being detected. The enhanced model includes the option of using sonar detection data from a minehunting sonar model such as MINERAY [7]. It reads an input data file containing a set of ranges with the cumulative detection probability shape for each range as shown in figure 4 below:

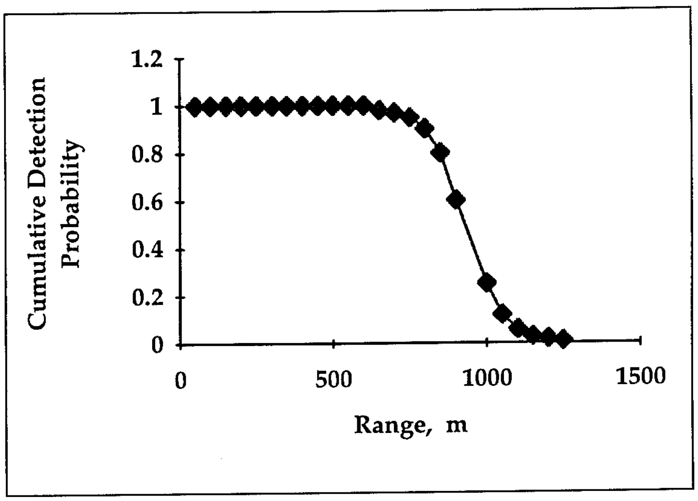

Figure 4: *Sonar cumulative detection probability*

It also reads the minimum and maximum detection ranges, the detection range for 90% probability, the sector angle, and the sector edge reduction factor. The probabilities for the given range are scaled to this shape.

Across the track, the detection probability is represented by a trapezoid shape as shown in Figure 5 below. The maximum detection width is given by

$$\textit{Maximum detection width} = 2 * \textit{Detection Range for 90\% probability} * \sin(\theta/2), \qquad (1)$$

where θ is the sector angle and the minimum detection width is given by

Minimum detection width = $(1-\eta)$ * *maximum detection width* (2)

where η is the edge reduction factor which allows for the reduction of detection probability at the edge of the sonar sector due primarily to the limited sonar coverage in this region and operator factors. For cross-channel distances less than the minimum detection width, the cumulative detection probability at a given range is determined by scaling from Figure 4 as described. Within the interim region between minimum and maximum detection width the detection probability is determined using linear interpolation; beyond maximum detection width the detection probability is set to zero.

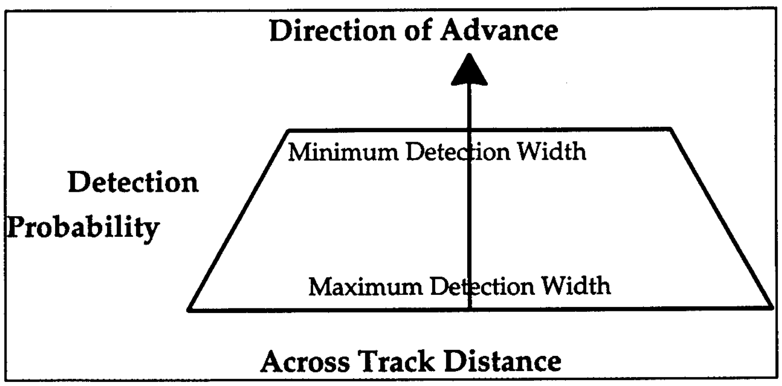

Figure 5: Detection probability as a function of cross track distance

2.4.2 Tactics

In Version 1 of the model the only minehunting tactic allowed was the progressive hunting sequence in which tracks were progressively hunted from one side of the channel to the other. This was changed from the initial version to include the effect of navigational error on track spacing. Thus the number of tracks is determined by

$$N = C/(D - 2\sigma) \quad (3)$$

where C is the channel width, D is the detection width and σ is the navigational error. N is rounded to the next higher integer. The track spacing is then computed from

$$d = C/N \quad (4)$$

Figure 6 shows an example of this tactic for a channel width of 1000 m and a detection width of about 550 m with navigational error ignored.

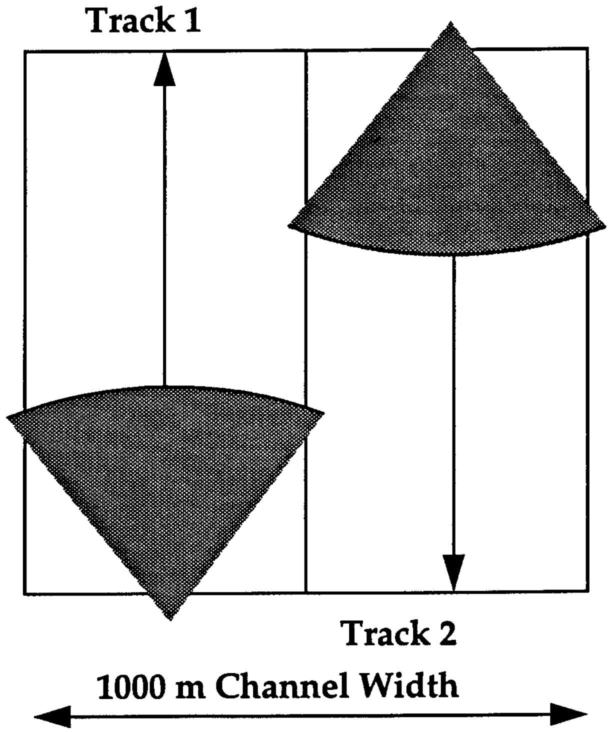

Figure 6: Minimum effort hunting tactic using progressive sequence across track

This tactic can be designated as a *minimum effort tactic* which attempts to produce uniform clearance across the whole channel since the fewest possible tracks are used. Effort can be simplistically considered as the sum of the lap transit time J(NL/v), where J is the number of runs per track, L is the track length and v the mean speed of advance, and the mine prosecution time (MT_P) where M mines are prosecuted each taking time T_P. For a given clearance level the same number of mines will be prosecuted so that the tactic which provides the minimum passes across the minefield will require minimum effort.

In Version 2 an additional minehunting tactic has been added [8]. This tactic allows the MCMV to hunt in uncleared waters only for the first track which is in the centre of the channel. Subsequent tracks are then hunted within the cleared area working outwards from the centre track. Each track is placed a distance ($2\sigma + \delta$) from the outer edge of the cleared area where δ is the MCMV's hover distance. The track spacing is determined by:

$$d = D/2 - 2\sigma - \delta \qquad (5)$$

and the number of tracks is given by:

$$N = 2(C/2d) + 1 \qquad (6)$$

where $(C/2d)$ is truncated to the nearest integer. Figure 7 shows an example of this tactic for a minefield width of 1000 m, detection width of 500 m, zero navigational error and hover distance of 100 m. Equation (6) predicts a total of 7 tracks, the first down the centre of the channel, the second at a cross-channel distance of 150 m, the third at 150 m and so on. This tactic ensures considerable overlap between tracks.

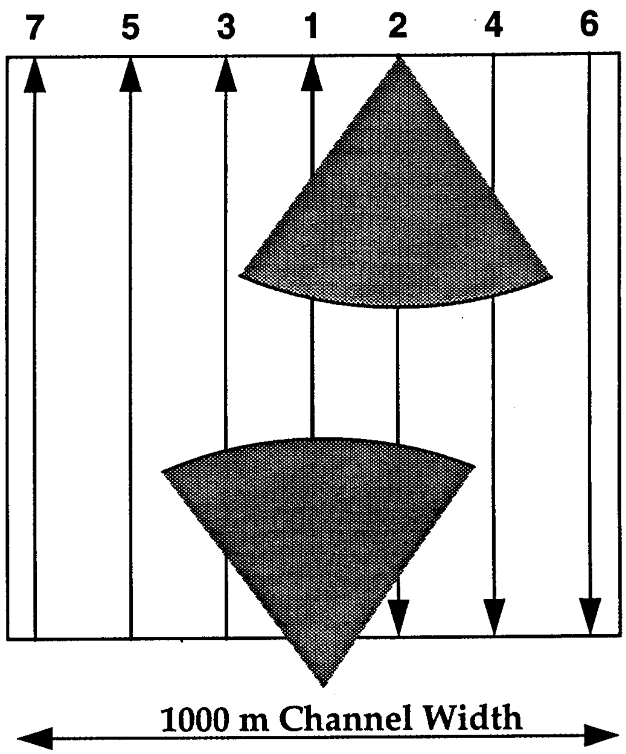

Figure 7: *Minimum risk hunting tactic*

This tactic can be considered as minimum risk since only on the first run is the minehunter hunting in uncleared waters. This assumes that there are mines throughout the region and not only in the channel. If there were mines only in the channel then a preferred tactic would be to hunt along a track outside the channel for the first lap, then to hunt sequentially inside the channel so that the MCMV is always in hunted waters.

2.4.3 Damage to MCMV

As it traverses the minefield the MCMV is at risk from mines which may be actuated by its passage. In the model whenever the MCMV's position is updated a check is made to see whether it has intercepted the actuation width of any live mines. If it has a further check is made to determine whether the MCMV is damaged. The model allows for the possibility that the MCMV can actuate and detonate mines with no risk to itself.

The interaction between the MCMV and a mine is defined by the parameters chahacteristic actuation width A, characteristic actuation probability B, dangerous front F, and damage probability B_d defined in NATO documentation [9]. The worst case scenario is assumed with all mines on ship count 1 with zero arming delays poised to fire.

2.4.4 Statistical Analysis of Simulation Results

Simulation models can compute average results over many replications of a particular scenario. It is important for the user to estimate the statistical accuracy of these results. This is achieved in the present model by using running variables which accumulate during the simulation. For example, clearance level for replication i is determined from

$$cl_i = d_i/n_i \tag{7}$$

where d_i is the number of mines disposed and n_i the number of mines in the field for replication i. The mean value for clearance level is given by:

$$CL = \sum_{i=1}^{R} d_i \,/\, \sum_{i=1}^{R} n_i = d_{all} \,/\, n_{all} \tag{8}$$

where d_{all} is the total number of mines disposed and n_{all} is the total number of mines placed in the field over all R replications. The standard error is then computed as:

$$SE = 1/R \times \left(\sum_{i=1}^{R} cl_i^{\,2} + R \times CL^2 - 2CL \sum_{i=1}^{R} cl_i \right)^{1/2} \tag{9}$$

that is the standard error is $\sigma/\sqrt{R}$ where σ is the standard deviation in a single measurement [10]. Rather than storing the individual cl_i values two running variables Σcl_i and $\Sigma cl_i^{\,2}$ are updated for each replication so that the standard error can be calculated when all replications are complete. Between each replication the numbers of mines and non-mines and their positions are varied, the outcomes of the critical events, and the delay times between these events,

2.4.5 Output from the Model

The output from the model has also been considerably expanded. MOEs such as clearance level have their statistical accuracies included. The average wait times for each resource, such as an ROV waiting for a charged battery are also included. The values of attributes used in the simulation run are also printed.

times for each resource, such as an ROV waiting for a charged battery, are also included. The values of attributes used in the simulation run are also printed. A listing of the MOEs output is given in Table 1. These are grouped into performance, average number of each procedure, and average times. More detail is given in section 3.3.

Table 1: Output Measures of Effectiveness

General Performance	**Average Timings**
Fraction of Mines Detected	Total Search Time
Fraction of Mines Undetected	Total Classification Time
Fraction of Mines Correctly classified	Total Identification Time
Clearance Level	Total Clearance Time
Clearance Rate	Total Wait Time
Average Procedure Count	
Average no. of Detections	
Average no. of Classifications	
Average no. of Identifications	
Average no. of Missed Mine-Like Objects	
Average no. of Disposals	

Graphical output is achieved by writing data for mine/non-mine positions and MCMV/ROV positions to a data file. This file can be accessed from an external Visual Basic program MH_GRAF.EXE which reads this file and then does a plot of the final replication of the simulation.

2.4.6 Sampling from Distributions

In Version 1 of the model, NAG and intrinsic VAX functions were used to provide random deviates. This has been replaced by using the random number generator of Scholz [11], which provides a set of independent random number streams which are also machine-independent.

To account for the effect of navigational error, it is necessary to sample from a gaussian distribution with a given mean and standard deviation. A routine was written using the Box-Muller algorithm [12], which uses the Scholz routine to provide a source of uniformly distributed variates.

To select numbers of mines and non-mines from their respective densities it is necessary to sample from Poisson distributions with means the average numbers of mines and non-mines in the field. This was done by first generating and storing vectors of Poisson probabilities with these means and then using the acceptance-rejection technique to select a random integer from the distribution. The Scholz routine is used to provide a source of variates.

Reaction times for the various states are also subject to random variations. In the model these reaction times are determined by sampling from a gamma distribution with two degrees of freedom for a given mean reaction time value. The gamma distribution, which is skewed in the positive time direction, is commonly used in simulation models for determining these delay times [13].

2.5 Model Limitations

The MHUNT model, like all models, is an abstraction from the real world. It was written for a high level evaluation of minehunting performance, and is a more simplified model than, e.g. the UK's MCS model [14]. The detailed specifications and explanatory text given in this Note expose the assumptions behind the model. The specifications were scrutinised and agreed by the Navy sponsor to be reasonable for the purposes of the MHC Effectiveness Study. The main simplifications and approximations made by the model are:

- The minefield is a two dimensional, rectangular area in which sets of identical mines and non-mines are located at random points, governed by their respective area densities.
- The MCMV is a point which moves through the minefield along straight, parallel tracks, except when it is necessary to divert from the track to approach a contact (mine or non-mine) which has been detected. The speed of the MCMV is constant in the search and classification phases of its operations. It is stationary from when an ROV is deployed to when the ROV is recovered. It approaches a detected contact along the radius, and returns to the track along the perpendicular.
- The MCMV navigation and track keeping error is modelled by adding a random number from a distribution with zero mean and given variance each time the MCMV position is updated, i.e. at each discrete event.
- The minehunting sonar is a sector shaped area pointing parallel to the track in detection mode, and a circular shape in classification mode. Detection is determined by means of a cumulative probability curve, and classification by correct classification probabilities for mines and non-mines. A detection probability reduction factor is included to take account of the reduction in detection probability in the wings of the detection envelope.
- Detection and classification ranges used by the MHUNT model are calculated by the MINERAY model [7] for a given set of target and environmental conditions. Thus the approximations made by the MINERAY model also apply to the MHUNT model. These include an isotropic mine target strength, average weather and sea bottom conditions and a uniform sound velocity profile.
- The MCMV only deals with a single contact at a time, i.e. contacts detected and classified as mines are disposed of by an MDC placed by the ROV (if identified as a mine), and then the next contact dealt with. A more realistic model would allow, in some circumstances, two or more contacts to be detected at the same time, their positions marked, and disposed of sequentially.
- The ROV is a point which always moves from the MCMV directly to the contact at a constant speed. Hydrodynamic effects and sea currents are not modelled. It always

finds the contact, and identifies it with a constant (within a simulation run) probability of being correct.

- Transit to and from the minefield in accordance with the MCMV operating cycle, and operational availability constraints due to equipment unserviceability and weather are not currently modelled (although the parallel process structure of the model would facilitate inclusion of these factors).
- The interaction between the MCMV and a mine is modelled by actuation and damage widths. If an MCMV comes within these widths, actuation and damage occurs with specified probabilities. These parameters are an approximation to TMSS actuation probability contour results [15], although the error in doing so is probably small.

Whilst it can be argued that the above assumptions place limitations on the accuracy of the results produced by the model, it must be stated that to produce valid results a model needs valid input data. The input data for the MHUNT model, described in Section 3.2 below, was highly variable in this regard, many parameters having to be estimated and some having uncertainties of several hundred percent. Thus it is believed that the model is an appropriate tool for comparative operational effectiveness studies of minehunting systems, but must be used judiciously.

3. Running the Model

3.1 IBM PC Model Operation

The model is run by entering MHUNT at the DOS prompt on an IBM PC or compatible. The model employs a menu-driven interface with options selected by entering a single character. The user is presented with the model's title screen containing program name, author information, place of origin, and date as shown in Figure 8.

```
*** MINEHUNTING SIMULATION MODEL - MHUNT ***

***   SIMULATES MCMV/ROV CLEARANCE OPERATION ***

WRITTEN BY : PETER RYAN & RICHARD WATSON  - 1994
        MARITIME OPERATIONS DIVISION
        MATERIALS RESEARCH LABORATORY
        DSTO-MELBOURNE
        DATE : 18/ 7/1994

TYPE RETURN TO START SIMULATION >>
```

Figure 8: Title screen for MHUNT model

On entering a return character the next screen, the master menu, is obtained as shown in Figure 9.

```
MINEHUNTING EVALUATION PROGRAM
-------------------------------------------

DEFINE SCENARIO                      (1)
SOLVE MCM PROBLEM                    (2)
DO GRAPHICS                          (3)
EXIT                                 (E)

ENTER OPTION >>
```

Figure 9: *Master Control menu for MHUNT model*

If a '1' is entered the Define Scenario Menu shown as Figure 10.

```
**** DEFINE SCENARIO MENU ****
-------------------------------------

READ DATA FROM FILE                        (1)
SET PARAMETERS MANUALLY                    (2)
PRINT PARAMETERS                           (3)
EXIT                                       (E)

ENTER OPTION  >>
```

Figure 10: *Define Scenario menu for MHUNT*

If a '1' is entered here the model prompts for a file name. This file contains all the data required to run the model. If a '2' is entered the manual input option is selected and the screen shown as Figure 11 is produced.

```
**** MANUAL INPUT MENU ****
-----------------------------------------------

SET UP MINEFIELD                    (1)
SET UP MINEHUNTER                   (2)
SET UP ROV                          (3)
SET UP BATTERY CHARGER              (4)
SET UP DISPOSAL CHARGES             (5)
SET UP SONAR INTERACTION            (6)
SET UP DAMAGE INTERACTION           (7)
EXIT                                (E)

ENTER OPTION >>
```

Figure 11: Manual Input Menu for MHUNT

After the input has been specified, either by reading data from a file or by entering it manually, the parameters can be checked by returning to the 'Define Scenario' menu and entering the character '3' (Figure 10). This produces the menu shown as Figure 12.

```
PRINT PARAMETER MENU
--------------------------------

MINEFIELD PARAMETERS                      (1)
MINEHUNTER PARAMETERS                     (2)
ROV PARAMETERS                            (3)
BATTERY CHARGER PARAMETERS                (4)
DISPOSAL CHARGE PARAMETERS                (5)
SONAR INTERACTION PARAMETERS              (6)
MCMV SAFETY PARAMETERS                    (7)
EXIT                                      (E)

ENTER OPTION >>
```

Figure 12: Print parameter menu

Once the user is satisfied that the scenario is defined properly, he can proceed to run the simulation by entering the character '2' from the master menu (Figure 9) to solve the simulation problem. This produces the simulation control menu in Figure 13.

```
        SIMULATION CONTROL MENU
        -----------------------------------------------

  Define MCM Tactics (NOT SET)                              (1)
  Number of MC Replications  [ 10]                          (2)
  Random Number Seed        [1891356973]                    (3)
  EXIT                                                      (E)

  ENTER option  >>
```

Figure 13: *Simulation control menu*

Figure 14 shows the screen produced during the execution of the MHUNT model. For each 10% of replications completed, the raw simulation results, such as numbers of mines detected and disposed, are printed to the screen. This can be used for debugging purposes and to provide an indication of completion time for the simulation run.

```
20% completed (    20) of    100 replications

 MINES : Total Mines in Field            =    200
Detected Mines                           =    172
Undetected Mines                         =     28
Mines classified as Mines                =    139
Mines classified as Non-Mines            =     33
Mines identified as Mines                =    139
Mines disposed by ROV                    =    139
Mines disposed by MCMV                   =      0
Mines disposed                           =    139

 NON-MINES: Total Non-Mines              =    209
Detected Non-Mines                       =    176
Undetected Non-Mines                     =     33
Non-mines classified as Non-Mines        =    163
Non-mines classified as Mines            =     13
Non-mines identified as Mines            =      0
Non-mines disposed by ROV                =      0

 MCMVS: MCMV Casualties                  =      0
```

Figure 14: *Screen produced during execution of MHUNT*

3.2 Input Data

The input data for the model is shown in Figure 15. It is divided into 7 parts - the minefield parameters, the MCMV parameters, ROV parameters, the battery charger parameters, the mine disposal charge parameters, the sonar/mine interaction parameters, and the MCMV/mine interaction parameters for mine actuation and damage.

```
GENERIC DATA USED FOR TESTING MODEL

****** MINEFIELD PARAMETERS ******
1891356973          ! Random no. seed
397204094           ! Multiplier
4                   ! No. of streams
99999               ! Offsets 1..nstream
999999
9999999
99999999
1000.               ! Minefield Width (m)
10000.              ! Minefield Length (m)
20.                 ! Minefield Depth (m)
DISCRETE            ! Seeding option for Mines
10                  ! No. of mines in field
.TRUE.              ! Mines placed at random positions
DENSITY             ! Seeding option for Non-Mines
1.0                 ! Density of Non-Mines (per sq km)

****** MCMV PARAMETERS ******
5.0                 ! Navigational error (m)
4.0                 ! MCMV Speed (detection mode) in knots
2.0                 ! MCMV Speed (classification mode) in knots
50.0                ! Increment for MCMV movement along track
5.0, 2.0, 8.0       ! Turn time (min) + Min/Max

****** ROV PARAMETERS ******
2                   ! Number of ROVs
B                   ! ROV Type (B or C)
2.0                 ! Speed in knots
20.0, 10.0, 30.0    ! Time to deploy ROV (min) + Min/Max
10.0, 5.0, 15.0     ! Relocation time (min) + Min/Max
10.0, 5.0, 15.0     ! Identification time (min) + Min/Max
10.0, 5.0, 15.0     ! Charge lay time (min) + Min/Max
20.0, 10.0, 30.0    ! Recovery time (min) + Min/Max
5.0                 ! Turnaround time
10.0                ! Decision time
```

```
****** BATTERY CHARGER PARAMETERS ******
2                  ! No. of battery chargers
3                  ! No. of batteries
300                ! Battery charge time (mins)
120                ! Battery life (mins)

****** DISPOSAL CHARGE PARAMETERS ******
30                 ! No. of disposal charges
30                 ! Arming delay (mins)
10                 ! Firing delay (mins)

****** SONAR INTERACTION PARAMETERS ******
.TRUE.             ! Sonar data read from file
.FALSE.            ! Rectangular parameters not used
sonar.dat          ! Sonar detection probability data file name
50.0               ! Min. detection range (m)
500.0              ! Max. detection range (m)
400.0              ! Range for 90% detection probability
90.0               ! Sector angle (deg.)
20.0               ! Sector edge reduction factor (%)
1.0                ! Max. detection probability
300.               ! Classification range (m)
300.               ! Classification width (m)
0.80               ! Classification probability for mine
0.90               ! Classification probability for non-mine
15.0, 10.0, 20.0   ! Mean classification time + Min/Max (min)
1.0                ! Relocation probability
1.0                ! Identification probability

****** MCMV/MINE INTERACTION PARAMETERS ******
50.0               ! Actuation width, A (m)
0.1                ! Actuation prob. (B)
50.0               ! Damage Width, F (m)
0.5                ! Damage Probability (Bd) if actuation occurred
100.0              ! Hover Radius (m)
200.0              ! Safe Fire Position (m)
```

Figure 15: Input parameters and typical values

3.2.1 Minefield Parameters

The minefield input data include random number seeding parameters, minefield dimensions, and seeding options for mines and non-mines. Note that for this minefield there are 10 mines placed randomly for each replication, whereas the number of non-mines is determined by sampling a Poisson distribution with mean 10 non-mines (non-mine density of 1 per sq km × 10 sq km).

3.2.2 MCMV Parameters

The MCMV input data include speeds for detection and classification modes of operation, navigational error parameters and also turn time. The increment is used for selecting detection ranges.

3.2.3 ROV Parameters

The ROV input data mainly consists of the times required to perform each of its mission steps, such as deployment and mine identification. Note that the ROV type specified here is battery-powered designated by 'B'. The alternative type of ROV permitted by the model is cable-powered designated by 'C'.

3.2.4 Battery Charger Parameters

The battery charger parameters include the number of chargers, total number of batteries, and charge time and battery life parameters

3.2.5 Disposal Charge Parameters

The disposal charge parameters comprise the number of disposal charges, the arming delay applied to each charge when laid, and the firing delay. This firing delay is the time delay applied to the firing after the MCMV has reached the safe distance.

3.2.6 Sonar Interaction Parameters

Here sonar cumulative probabilities as a function of range are read from an external data file. The remaining parameters specify the limits of contact detection, classification parameters, and the relocation and identification probabilities.

3.2.7 MCMV/Mine Interaction Parameters

These parameters are used to determine whether (a) a mine is accidentally actuated if the MCMV passes close by and (b) if the MCMV is damaged by such a mine actuation. The safe fire position defines the distance the MCMV has to be placed from the mine before the disposal charge is fired remotely.

3.3 Output Results

The model output can be written either to the DOS screen or to a file. In either case there are 4 pages of output data contained below in Figure 16. This output was produced using the above input data set for 500 replications of the model.

MEASURES OF MINEHUNTING EFFECTIVENESS

Fraction Detected	=	77.20 % (+/- 0.63%)
Fraction Undetected	=	22.80 % (+/- 0.63%)
Mines Classified Correctly	=	62.22 % (+/- 0.73%)
Clearance Level (TOTAL)	=	62.52 % (+/- 0.71%)
Clearance Level (SAFE)	=	62.88 % (+/- 0.77%)
Countermeasures Risk	=	0.22 % (+/- 0.25%)
Expected Casualties	=	0.014 (+/- 0.01)
Avge no. detections	=	15.34 (Mines: 7.72 Non-Mines: 7.62)
Avge no. mine classifications	=	6.97 (Mines: 6.22 Non-Mines: 0.75)
Avge no. mine identifications	=	6.22 (Mines: 6.22 Non-Mines: 0.00)
Avge no. missed milcs	=	4.45 (Mines: 2.28 Non-Mines: 2.17)
Avge no. mine disposals	=	6.25 (By ROV: 6.22 By MCMV: 0.03)
Avge no. mine disposals (SAFE)	=	6.20
Avge no. non_mine disposals	=	0.00
Avge no. non_mine disposals (SAFE)	=	0.00

Figure 16(a): Page 1 of output- mean measures of effectiveness for minehunting

MEASURES OF MINEHUNTING EFFECTIVENESS - TIMES

Search Time	=	2 hrs 26 mins +/- .5% (12.0% of total)
Classification Time	=	4 hrs 15 mins +/- 1.1% (20.9% of total)
Identification Time	=	3 hrs 44 mins +/- 1.3% (18.3% of total)
Disposal Time	=	8 hrs 51 mins +/- 1.2% (43.5% of total)
Total Clearance Time	=	20 hrs 20 mins +/- 1.0% (+ MCMV Wait Time)
Wait time	=	1 hrs 5 mins
Avge time BC1 waiting for a battery	=	119.14 mins
Avge time BC2 waiting for a battery	=	216.24 mins
Avge time spare ROV waiting for a battery	=	96.13 mins
Avge time next ROV waiting for a battery	=	68.11 mins
Avge time MCMV waiting for ROV	=	34.53 mins
Clearance Rate	=	0.492 sq km/hr
Average Advance Speed	=	0.141 knots
Total Distance (Lap Tracks)	=	20000.0 m
Total Distance Travelled	=	23735.9 m

Figure 16(b): Page 2 of output - times for processes

SUMMARY OF SIMULATION RUN

Number of Tracks	=	2
Average No of Runs/Track	=	1.00
Minefield Width	=	1000.0 m
Minefield Length	=	10000.0 m
Track Spacing	=	500.0 m
Average Mine Density	=	1.000 per sq km
Average Non-Mine Density	=	.979 per sq km
Number of Replications	=	500
Hunting Tactic	=	MINIMUM EFFORT
Extra Track at Edge	=	NO
Elapsed CPU Time	=	141.21 secs

Figure 16(c): Page 3 of output - summary of simulation

VALUES OF ATTRIBUTES USED IN THE RUN

No of battery chargers = 2   No of batteries = 3
No of ROVs = 2   ROV type = B

90 % Detection Range = 400.0 m   Detection Width = 565.7 m
Max Detection Range = 625.0 m   Min Detection range = 25.0 m
Classification Range = 300.0 m

TIMES IN MINUTES	MEAN	MIN	MAX
MCMV Transit Time to Op Area	240.0	120.0	360.0
Contact Classification Time	15.0	10.0	20.0
Contact Identification Time	10.0	5.0	15.0
MDC Laying Time	10.0	7.5	15.0
ROV Recovery Time	20.0	10.0	30.0
MDC Arming Time	30.0	30.0	30.0
MDC Firing Time	10.0	10.0	10.0
Battery Charge Time	300.0	225.0	450.0
Spare ROV Turnaround Time	5.0	3.8	7.5
ROV Decision Time	10.0	5.0	15.0
Next ROV Turnaround Time	5.0	3.8	7.5

*** RESULTS FILE = mhunt.out

Figure 16(d): Page 4 of output - values of attributes used in simulation

3.3.1 Page 1: Mean Measures of Effectiveness

This page contains the averaged MOEs for fraction of mines detected, cleared etc. together with the average number of times each process such as a mine classification was carried out. Note that the clearance level designated TOTAL denotes the clearance level for all replication, whereas that designated SAFE denotes the clearance level for those replications where the MCMV remained undamaged.

3.3.2 Page 2: Mean Times for Minehunting Performance

This page contains the time measures of effectiveness (in hours and minutes) such as average total clearance time. The average wait times for each of the processes in minutes are also included. These results can indicate whether the clearance operation is adversely affected by time delays.

The clearance rate is calculated by dividing the area cleared by the total clearance time. The average speed of advance is computed from the total distance travelled across the minefield (20000 m for one run along each of two tracks). The total distance travelled by the MCMV is to be contrasted with the total lap track distance and provides an indication of the off-track excursions made by the MCMV while classifying and disposing of mines.

3.3.3 Page 3: Summary of Simulation

This page provides a summary of the simulation run including tactics data, minefield data, and elapsed CPU time used by the computer. Here a tactic of one run on each of two 500 m wide tracks is used, determined from the minimum effort tactic. The option of including an extra track close to the edge of the channel is disabled.

3.3.4 Page 4: Values of Attributes

This page includes the attribute values used in the simulation, such as the number of battery chargers and total number of batteries. The ranges of possible values from minimum to maximum for each of the reaction times are also included. The model samples delay times from within these limits.

3.4 Event State Trace

The event-state trace is an optional output from single replication runs of the simulation. It provides the time each event occurs, the event name, and the value of each event pointer element. All simultaneous events are listed, followed by a state trace, with the system variables also listed after the state trace. The event-state trace is very useful for verifying that the program operates as specified by the directed graph, and for debugging. Further, once the model has been verified and validated, the program can be run in event-state trace mode to better understand the actual system operation.

Complete details of the event state trace are provided in Annex D.1

3.5 Graphical Output

Graphical output can be obtained by writing an ASCII graphics external file. This file can then be accessed by an external Visual Basic code and a reconstruction of the last replication performed can be displayed on the screen.

Details of the graphics file format are provided in Annex D.2. A sample plot is shown as Figure 17 with the key included.

The MHUNT model has been adapted to work under a Visual Basic interface. Visual Basic uses Microsoft Fortran Dynamic Link Libraries (DLLs) to replace the Fortran DOS program.

4. Discussion and Conclusion

Modelling and simulation are powerful tools with which to study MCM. Simulation models have been developed both for the target/mine encounter and also for minefield clearance operations. Since the simulation is flexible, these models can be changed to reflect improved knowledge and it provides a low cost alternative to carrying out costly trials.

A discrete-event simulation model has been described for naval minehunting. The model functions by imitating the real world minehunting process in a simplified fashion. The minehunting procedure is reduced to a set of connected, discrete events and the outcome of each of these is determined by random sampling. Measures of effectiveness, such as clearance and risk, can be determined by executing many replications of a particular scenario.

The model was specified using a modified state transition diagram methodology and developed with the assistance of third-party event-management software. The model incorporates multiple parallel processes for the MCMV, MDC, battery charger, spare ROV and next ROV. This software enables the parallel processes to be modelled using linked lists of future events and wait states.

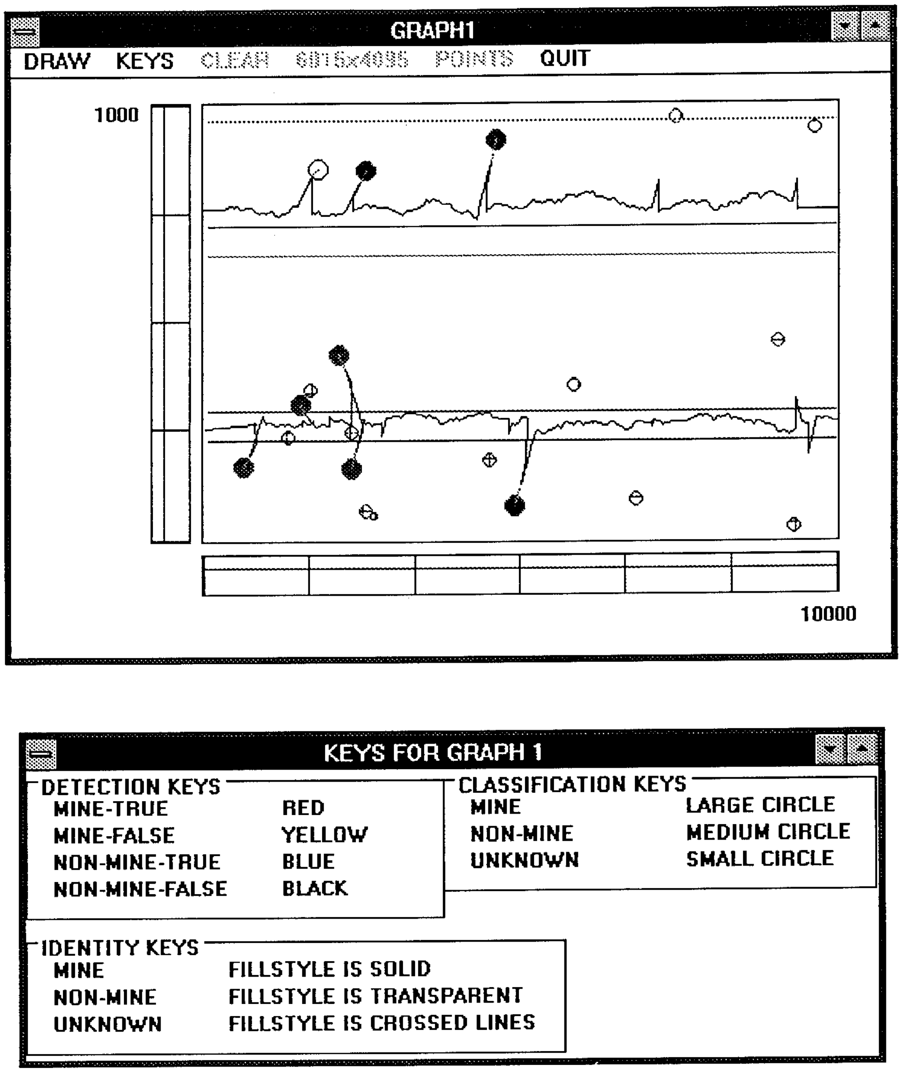

Figure 17: Graphical output and description key

5. References

1. Function and Performance Specification, Mine Warfare Command Support System. (1992). Document No. A013789, Dept. of Defence, Navy Office, Canberra, ACT, Australia.

2 Gaylor, K. and Ryan, P.J. (1991).
A Monte Carlo simulation of naval minesweeping, MRL Research Report MRL-RR-91-2 (Restricted) Maribyrnong, Vic: Materials Research Laboratory.

3. Ryan , P.J. (1993).
A Monte Carlo simulation of naval minehunting, MRL Tech. Report MRL-TR-92-40 (Restricted)

4. Ryan, P.J. and Gaylor, K.J. (1991).
Comparison between deterministic and Monte Carlo methods of evaluating uncountered minefields, MRL Tech. Report MRL-TR-91-19 (Restricted)

5. Watson, R.B. and Ryan, P.J. (1994).
Effectiveness study of minehunting systems, Final Report to Mine Hunter Coastal Project Director under Task NAV 92/398.

6. Clymer, J.R. (1990).
Systems Analysis Using Simulation and Markov Models, Prentice-Hall Inc., New Jersey.

7. Tuovila, S.M. (1985).
Searay sonar simulation model, Laboratory Report 3240-U-85-01 Naval Coastal Systems Center, US

8. Wood, D., Warton, W., and Kemister, G. (1993).
The operational effectiveness of the minehunter coastal ASU Working Paper MHC1, Force Development & Analysis, FDA 92-2889 (Confidential)

9. *Mine Countermeasures Operations: Planning and Evaluation.* ATP6(B), Vol. 2 (1991). (NATO Confidential)

10. Gould, H. and Tobochnik, J. (1988).
An Introduction to computer simulation methods: Part 2, Addison-Wesley Publishing Company, US.

11. Scholz, M.L. (1990).
A procedure for generating run-synchronised disjoint streams of random numbers for use in simulation. (WSRL Technical Note WSRL-TN-46/89). SA: Salisbury

12. Box, G.E.P. and Muller, M.E. (1958).
A note on the generation of random normal deviates. Ann. Math. Statistics. 29, 610-611

13. Law, A.M. and Kelton, W.D. (1982).
Simulation modeling and analysis, Mc-Graw-Hill Book Co.

14. British Aerospace (1987).
Minefield Clearance Simulation, Sonar Model User Guide, BT22689

15. Field, G. et al (1993).
Total Mine Simulation System, Version 3.4, DRA TM(USM) 92129

Annex A: Clymer's Methodology

The MHUNT model was specified by Clymer's directed graph notation, which is a form of state transition diagram [A1]. It incorporates Clymer's event management software to control its dynamic behaviour. This notation and software are described in this Annex.

A.1 Clymer's Directed Graph Notation

A discrete event simulation model may be regarded as a finite state machine, which is a hypothetical machine which can only be in one of a given number of states at a time. In response to an input, the machine may generate an output and/or change state. Both the output and the new state are purely functions of the current state and the input. A state transition diagram (STD) is one means of defining a finite state machine. One form of STD, the activity cycle diagram, has been used to specify simulation models for many years [A2]. It is noteworthy that in recent years the STD has taken on a new importance as a tool for specifying the external behaviour of complex software systems such as distributed and real-time systems [A3] and object-oriented systems [A4]. Significant extensions to the range of concepts describable by the STD have been made by [A5], mainly for specifying complex real-time software systems but also applicable to simulation modelling.

Clymer's directed graph notation is a form of STD which represents the operational behaviour of a system containing parallel (concurrent) processes. Each process is a subordinate finite state machine, and the state of the total system is a combination of the states of each subordinate machine. Harel ([A5]) uses the term *orthogonal* to describe this type of decomposition. If a system described using Clymer's notation was described by a conventional STD, which does not use orthogonal decomposition, the number of states would be greater and the diagram would be much harder to understand.

A parallel process in Clymer's notation is a sequence of states and events, events marking points in time when a change of state occurs. (In Harel's notation, the term *transition* denotes a change of state, and the term *event* generally means a message sent from one process to another, which may or may not cause a change of state). Clymer distinguishes four kinds of states, although circles are used for all of them (unlike activity cycle diagrams). They may be distinguished as follows, however:

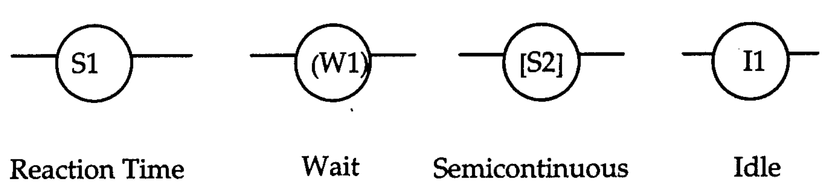

Figure A.1: States used by Clymer

Reaction-time states represent the length of time a resource is performing a particular function. In simulation models, reaction times are often computed by a random-variable generator. In a queueing application, for example, a server serving a customer would be in a reaction-time state. (They are equivalent to *active states* in activity cycle diagrams).

Wait states represent the time a process waits for a logical condition to be satisfied, and the process will remain in this state until the condition is satisfied. Harel (ref. [A5]) terms this a *guard condition*, which can also determine the state to which a reaction-time state transitions after the reaction-time. In a queueing application, for example, a customer waiting in a queue for service would be in a wait state. (They are equivalent to *dead states* in activity cycle diagrams). The logic that activates the event may be in the event itself or elsewhere. In the latter case the state is said to be *passivated*, and the process will remain in it until an appropriate message from another process is received.

A *semicontinuous state* approximates the continuous behaviour of a detailed model of system operation. State variables associated with this kind of state are updated frequently to model a process that varies continuously. In the MHUNT specification, semicontinuous states are not used.

An *idle state* is a type of wait state which represents a period of time a process is waiting for one or more other processes to be completed before an assemble event can occur.

Clymer's notation for a simple parallel process is thus as follows:

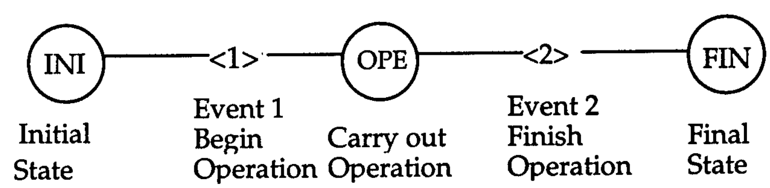

Figure A.2: Clymer notation for parallel process

Clymer also introduces a special notation for the direct execution of events, as follows:

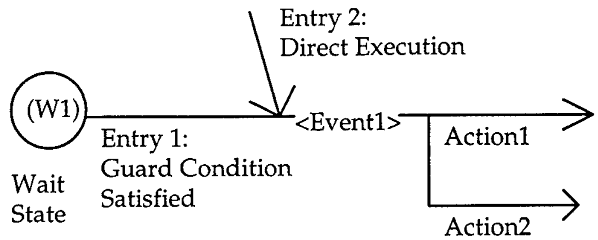

Figure A.3: Clymer notation for direct execution of events

The direct execution of events corresponds to a message from another process which causes a transition from a wait state irrespective of whether the guard condition logic is satisfied, or a premature (i.e. before the reaction time is up) transition from a reaction time state. The diagram above shows a transition (Event 1) from a wait state W1 which occurs either after a guard condition is satisfied (Entry 1) or after a message is received (Entry 2). The action following the transition (two alternative actions are shown in the diagram, but there may be any number) may be determined by the guard condition or the message parameters.

In Clymer's notation, particular kinds of events are associated with the splitting of a process into two or more parallel processes or the synchronisation of two or more parallel processes into one. These are termed split events and assemble events, respectively, and their notation is shown below as Figure A.4:

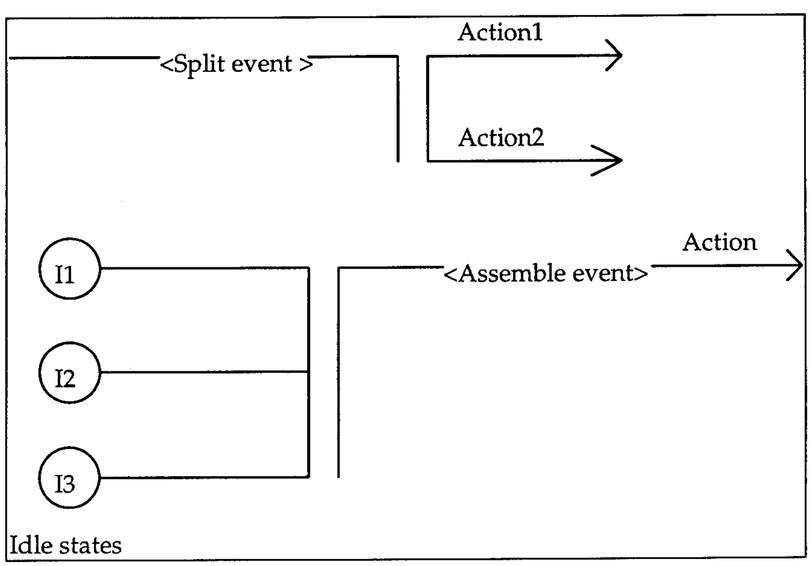

Figure A.4: Split and assemble events

A.2 Clymer's Event Management Executive Software

The event management executive software provided by Clymer is stated (pg 13 of ref. [A1]) to use a combination of event-scheduling and modified activity scanning. These methods are described by Pidd ([A2]). Clymer's method actually bears considerable resemblance to Pidd's so-called three phase method. A flow chart of Clymer's MAIN simulation routine is shown below.

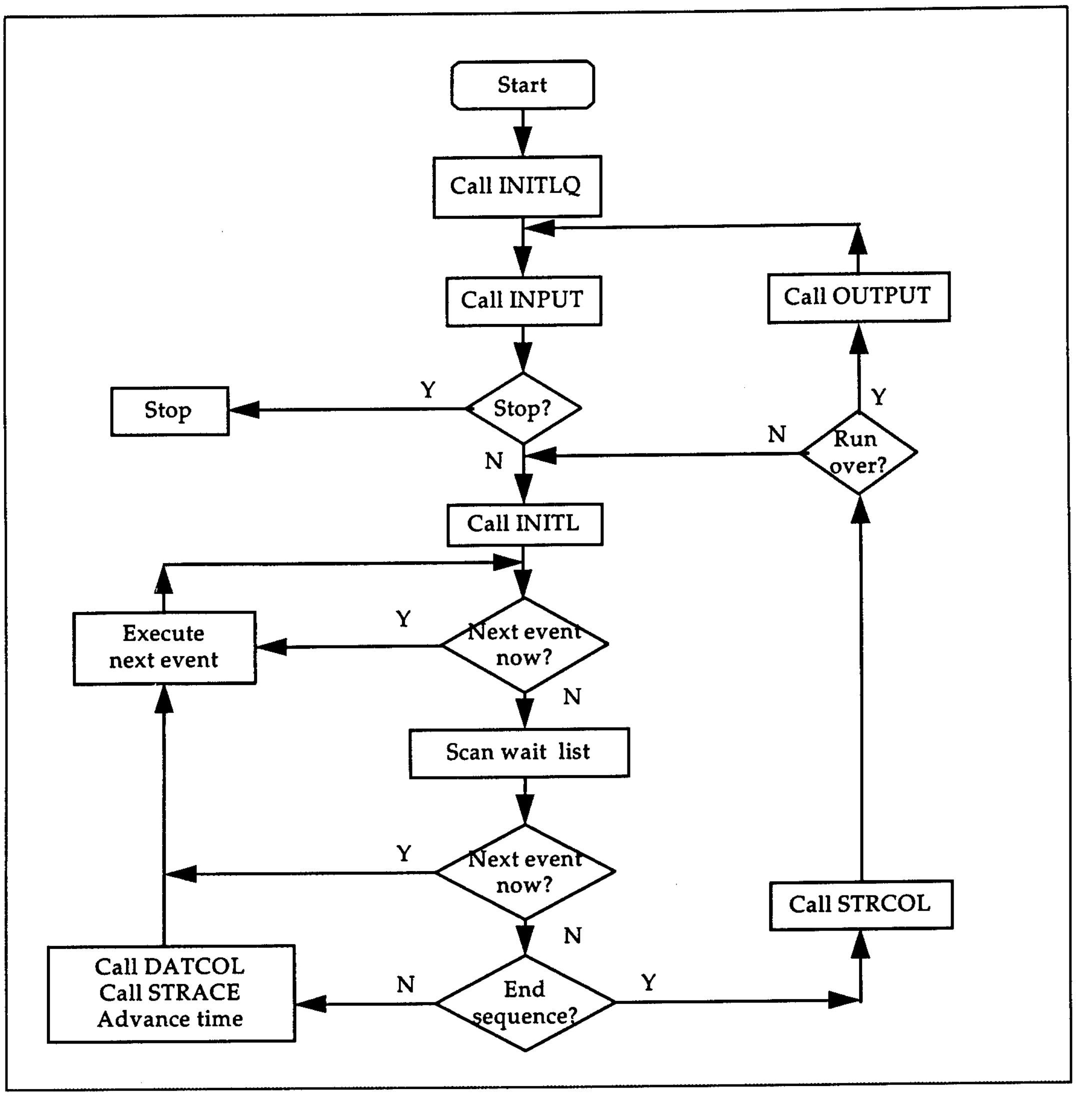

Figure A.5: Flow chart of event management software from Clymer (ref. [A1]).

Clymer's event management software has two linked lists of events: the *future events list* and the *wait list*. At each stage of the simulation cycle, all event subroutines scheduled to occur at the current simulated time are executed. Then each event on the wait list is tested to see if its occurrence logic is now satisfied. Occurrence of wait events is tested within their particular event routine. Note that an event can be scheduled to occur immediately after another event, by the first event putting it on the future events list with no time delay. In the MHUNT application, event 22 in the Next ROV Process (decide which ROV to use next) directly executes event 19 in the Spare ROV Process in this way.

A.3 References

A1. Clymer, J.R. (1990), *Systems Analysis Using Simulation and Markov Models,* Prentice-Hall

A2. Pidd, M. (1992), *Computer Simulation in Management Science,* Third Edition, Wiley

A3. Davis, A.M. (1988), *A Comparison of Techniques for the Specification of External System Behaviour,* Communications of the ACM, Vol. 31, No. 9, pp 1098-1115.

A4. Rumbaugh, J. et al., (1991), *Object-Oriented Modeling and Design,* Prentice Hall.

A5. Harel, D. (1987), Statecharts: a visual formalism for complex systems, *Science of Computer Programming,* Vol. 8, pp 231-274.

Annex B: Module Descriptions of MHUNT Model

B.1 Overview of model

The MHUNT program consists of a set of 10 modules described briefly below:

MHunt	Contains input routines
MH_Clym	Event-management routines from Clymer
MH_Event	Contains event scheduling for each parallel process
MH_Solve	Event routines
MH_Res	Converts the raw data into measures of effectiveness (nos. of mines disposed is converted to clearance level, for example).
PC_Graph	Writes ASCII file for graphics
MH_Sonar	Sonar detection routines
MH_Rand	Random number generator routines
MH_Aux	Auxiliary routines
MH_PC	Routines to emulate VAX FORTRAN intrinsic routines

Short descriptions of each routine in these modules are provided below. These are Fortran subroutines unless indicated otherwise.

B.2 Module: MHunt

B.2.1 Define Scenario

Displays menu listing selections, reads option chosen, then acts upon choice.

B.2.2 Get Manual Input

Routine to read in input data to define the scenario manually. This routine calls routines B.2.4-B.2.10 below.

B.2.3 Set Defaults

Sets default values for flags and numeric constants, initialises the random number streams, and sets string constants for file names.

B.2.4 Set Up Minefield

Sets the minefield dimensions, minefield seeding type, numbers/densities of mines and non-mines.

B.2.5 Set Up Hunter

Sets the hunter variables such as speed, navigation error etc.

B.2.6 Set Up ROV

Sets the ROV variables such as speed, times for deployment and recovery etc.

B.2.7 Set Up BatC

Sets the battery charger variables such as number of chargers, time to charge etc.

B.2.8 Set Up MDC

Sets the number of mine disposal charges and arming delay.

B.2.9 Set Up Sonar Interaction

Reads in the file containing sonar/mine interaction parameters.

B.2.10 Set Up Damage Interaction

Sets the damage interaction parameters for the MCMV.

B.2.11 Get Information From File

Sets the scenario by reading the parameters from an external input ASCII data file. This is an alternative to the manual input.

B.2.12 Print Parameters

Displays print-menu, reads choice, then acts upon choice which calls subroutines to print the relevant parameter values. Calls the following two routines.

B.2.13.Print Rectangular Parameters

Prints parameters for sonar/mine interaction if the 'rectangular' option for sonar performance has been specified.

B.2.14. Print Sonar Parameters

Prints parameters for sonar/mine interaction if the sonar option has been set. This reads a file containing detection probabilities as a function of range from the MCMV.

B.2.15. Read Sonar Probs

Reads file of preset name for setting sonar parameters.

B.2.16. Reset_Times

Resets time parameters.

B.3 Module: MH Clym

B.3.1 MHunt Clymer

Controlling routine for simulation.

B.3.2 Print Q

Prints the wait list and event queues.

B.3.3 Initl Q

Initialises the linked lists for each process' event queues.

B.3.4 Remove

Removes events from queues

B.3.5 RMVWTQ

Removes events from wait list.

B.3.6 FileWT

Schedules wait state for a given process.

B.3.7 FileVT

Schedules event for a given process

B.3.8 UnFile

Removes specified elements from all linked lists.

B.3.9 NxtEvt (Function)

Determines the next event to occur.

B.4 Module: MH_Event

B.4.1 Start MCM Op

Starts the MCM operation: displays selective information, sets parameters, then calls other routines.

The following 5 routines represent the parallel processes: MCMV, Mine Disposal Charge, Battery Charger, Spare ROV, Next ROV.

B.4.2 MCMSim

Processes the determined event for the MCMV

B.4.3 MDCSim

Processes the determined event for the MDC.

B.4.4 BATSim

Processes the determined event for the battery charger.

B.4.5 SPRSim

Processes the determined event for the Spare ROV.

B.4.6 NERSim

Processes the determined event for the Next ROV.

B.4.7 Events

Calls particular process subroutine.

B.4.8 DatCol

Updates data collection counters for the time between the last and current events of the operational sequence.

B.4.9 ETrace

Prints the descriptor for the given event.

B.4.10 ReadInput

Sets up and displays a menu, reads and acts upon choice then, possibly, changes one or more sets of parameters.

B.4.11 RWOutput

Prints report

B.4.12 STrace

Prints selective trace information, possibly to a file.

B.4.13 StrCol

Collects run statistics at the end of each operational sequence.

B.5 Module: MH_Solve

B.5.1 Define Simulation

Presents menu and acts upon the choice: sets tactics, no. of replications, random no. seed.

B.5.2 Define Tactics

Presents menu and acts upon the choice.

B.5.3 Next Encounter (Function)

Function which returns the next mine encountered in the track.

B.5.4 Calculate Running Totals

Updates the numbers of mines/non-mines detected, classified, disposed etc. and other statistical variables.

B.5.5 Check Detection

Checks whether the given object is detected.

B.5.6 Detect Milc

Samples distribution to determine if a given object is detected.

B.5.7 Move MCMV To Classification

Moves the MCMV to the classification distance.

B.5.8 Check Classification

Checks whether the contact is classified by sampling from a uniform distribution.

B.5.9 Move MCMV To Hover

Moves the MCMV to the hover position.

B.5.10 Launch ROV

Launches the ROV from the MCMV.

B.5.11 Move ROV To Contact

Moves the ROV to the contact location.

B.5.12 Check Identification

Checks whether the contact is identified.

B.5.13 Move MCMV To Safety

Moves the MCMV to a safe position after the ROV has been recovered.

B.5.14 Return MCMV To Track

Returns the MCMV to its intended track after completing the disposal operation.

B.5.15 Move MCMV To End Of Track

Moves the MCMV to the end of the track because there are no more mine-like objects left in the track.

B.5.16 Check Disposal

Checks whether the mine has been disposed.

B.5.17 Milc In Detection Sector (Function)

Function returning true if a given contact is within the sonar's detection sector.

B.5.18 Milc In Classification Sector (Function)

Function returning true if a given contact is within the sonar's classification sector. Note this only uses the parameter *classification distance.*

B.5.19 Update MCMV Position

Updates the MCMV's position by adding a randomly-generated value from a gaussian distribution whose standard deviation is given by the navigational error. The MCMV's current position is stored for graphical output.

B.5.20 Check Damage MCMV

Checks whether the MCMV has passed through a mine's damage radius and has been damaged.

B.5.21 Update ROV Position

Updates the ROV's position. The ROV position is stored for graphical output.

B.5.22 Initialise Encounter

Sets all statistical variables to zero.

B.6 Routines of MH_Res

B.6.1 Initialise Results

Initialises the results before running the simulation

B.6.2 MHunt Results

Prints statistical variables each 10% of total replications completed. These include no. of mines in field, no. detected, no. classified etc.

B.6.3 Print MOES

Calculates then prints measures of effectiveness derived from the simulation. These can optionally be printed to a file.

B.7 Routines of PC_Graph

B.7.1 Write Graphics File

Writes data for object positions and MCMV and ROV movements for future graphics processing.

B.8 Module: MH_Sonar

B.8.1 Detect Milc Sonar Probs

Determines whether a contact is detected by using the full sonar probability data.

B.8.2 Reduction Factor (Function)

Calculates the reduction in detection probability experienced at the edge of the sonar sector.

B.8.3 Prob Detect (Function)

Determines the probability at a given range using linear interpolation.

B.9: Module: MH_Rand

B.9.1 Gaussian

Returns a random number selected from a Gaussian distribution.

B.9.2 Init Poisson

Initialises the Poisson distribution streams.

B.9.3 Poisson (Function)

Selects a random number from a given Poisson distribution which has been initialised by Init Poisson.

B.9.4 RandVal (Function)

Returns a uniform random number - calls Randex which uses double precision.

B.9.5 SRandIni

Initialises a given number of independent random number streams.

B.9.6 RandEx (Function)

Returns a uniform random number from a given stream.

B.9.7 Ifactor (Function)

Function used by Randex.

B.9.8 LongMod (Function)

Function used by Randex.

B.10 Module: MH_Aux

B.10.1 ClrScr

Subroutine to clear screen.

B.10.2 Convert Time

Converts time in minutes to hours and minutes.

B.10.3 UpDate Time

Updates the simulation time.

B.10.4 Reset Minefield

Sets the numbers of mines and non-mines from given Poisson distributions.

B.10.5 Set Milc Positions

Sets the positions of the mines and non-mines in the field.

B.10.6 Initialise Milc Attributes

Initialises milc attribute flags such as detected status.

B.10.7 Normal (Function)

Returns a random number selected from a probability distribution with a given mean and standard deviation.

B.10.8 SD (Function)

Calculates standard deviation of each result given the statistics and the number of replications.

B.10.9 Gamma (Function)

Generates random value from gamma distribution.

B.10.10 ErLang (Function)

Generates random value from Erlang distribution (not used in current version).

B.10.11 Rnd (Function)

Not used in current version.

B.11 Module: MH_PC

These modules mimic VAX FORTRAN routines by using calls to Microsoft Fortran routines.

B.11.1 Str$Upcase

Converts a character string to upper case.

B.11.2 Secnds (Function)

Returns time in seconds.

B.11.3 Date

Returns date as a character string.

B.12 Include Common Blocks

B.12.1 Batc.cmn

Contains the battery charger variables.

B.12.2 Control.cmn

Contains flags controlling the simulation operation.

B.12.3 Files.cmn

Contains names for input and output files.

B.12.4 Interact.cmn

Contains sonar and mine interaction parameters.

B.12.5 MCMV.cmn

Contains MCMV parameters.

B.12.6 MDC.cmn

Contains Mine Disposal Charge parameters.

B.12.7 Mfield.cmn

Contains minefield parameters.

B.12.8 MHunt.cmn

Contains variables used by event management routines.

B.12.9 Rand.cmn

Contains random number parameters.

B.12.10 Results.cmn

Contains results - measures of effectiveness for minehunting.

B.12.11 ROV.cmn

Contains ROV parameters.

B.12.12 Running.cmn

Contains intermediate statistics such as mines detected etc.

B.12.13 Sonar.cmn

Contains sonar performance data.

B.12.14 Tactics.cmn

Contains tactics parameters.

B.12.15 Block Data : BLKDT1

This contains default values for reaction times, battery chargers, no. of batteries, max no. of contacts, no. of ROVs and types of ROVs.

Annex C: Flowcharts for Processes in MHUNT Model

C.1 MCM Process

This section contains the key sequences of events undergone by the MCMV during a minehunting operation. These are (a) contact detection, (b) contact classification, (c) identification, and (d) mine disposal. Figure C.1 shows the whole sequence of events for contact investigation. Briefly, when a contact is encountered the detection method is set, the detection of the contact is checked, then, if a detection is made, the contact is classified and prosecuted if identified as a mine. Following this the MCMV returns to the track.

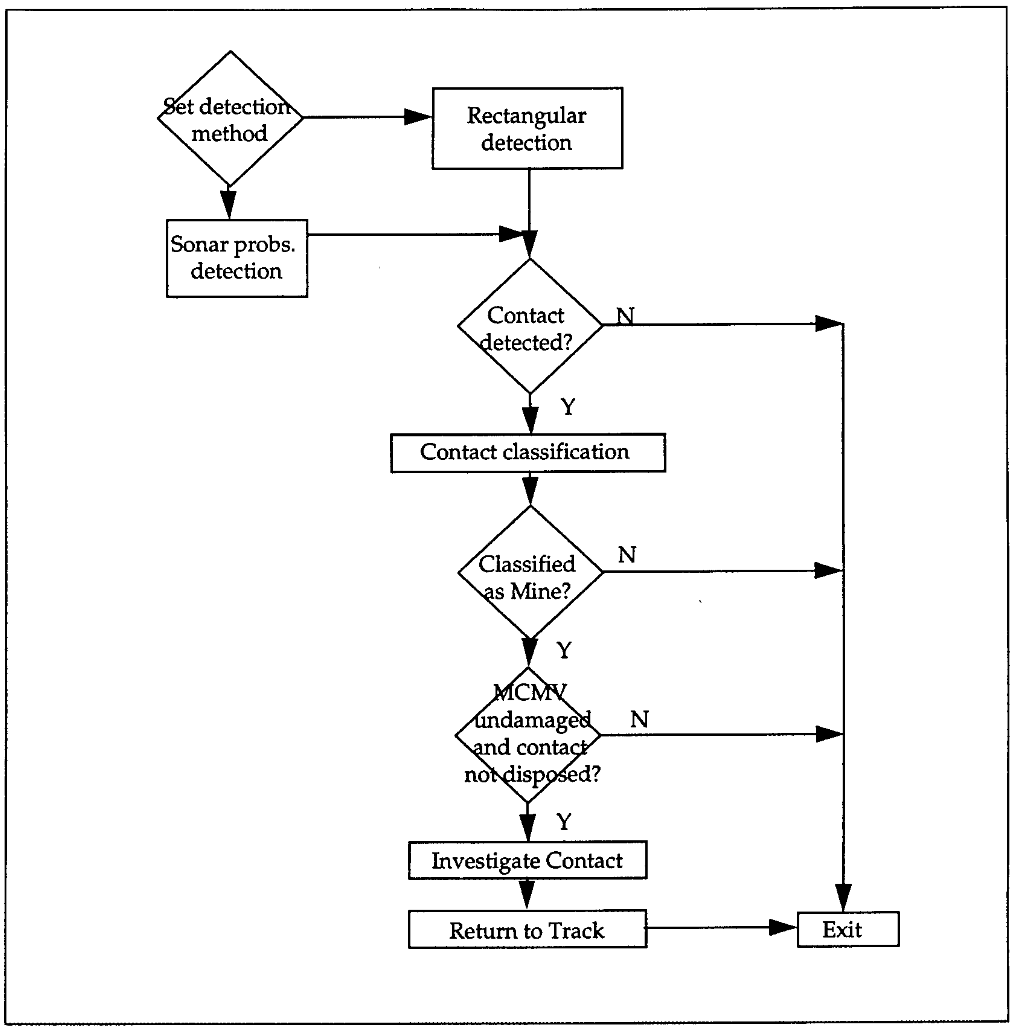

Figure C.1: Flowchart of MCM Process

C.1.1 Detection using Sonar probabilities

There are two options for sonar detection - either sonar cumulative probabilities as a function of range can be read from a file or a fixed probability for the whole sonar sector defined by the detection range and sector angle can be used. In the first of these the MCMV is moved along a set of ranges towards the contact until detection has occurred or until the contact has passed out of the sonar's detection sector. If there is a possible contact in the sonar "shadow" at the start of a track (the region outside the sonar's detection sector that would have been insonified had the sonar been operating before the start of the track) it is also assumed that this object can be detected. In this case only one chance is allowed for contact detection.

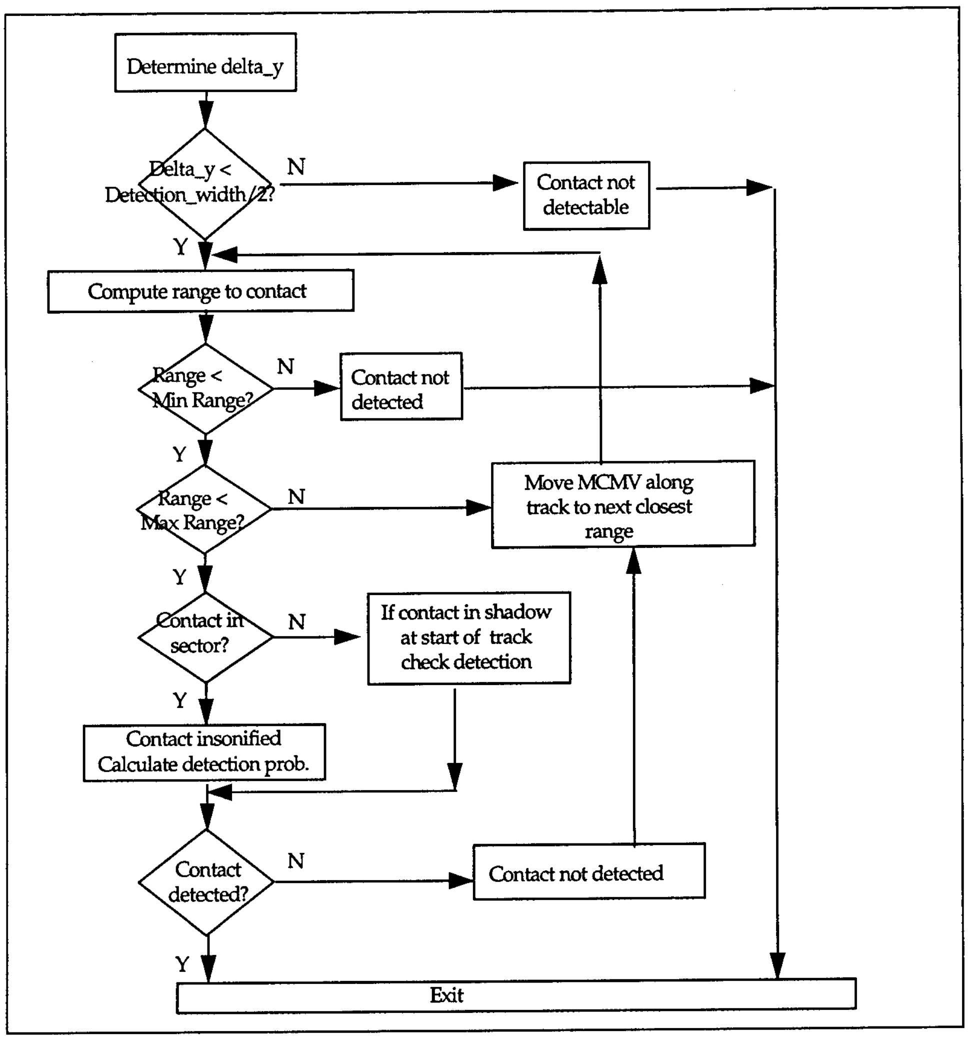

Figure C.2: Flowchart of sonar detection subprocess

C.1.2 Detection using Fixed probabilities

If this option is selected a fixed value of detection probability is applied throughout the detection sector. A check is first made as to whether the object is within the sonar sector. If it is then a check is made as to whether it is detected, using random sampling. Alternatively if the next object in the track is outside the sector, the MCMV is moved along the track until the contact is within this sector and detection is checked. If this object is outside the detection width the object is deemed undetectable and the next object in the track is investigated. Again it is assumed that an object in the "shadow" region at the start of a track can be detected.

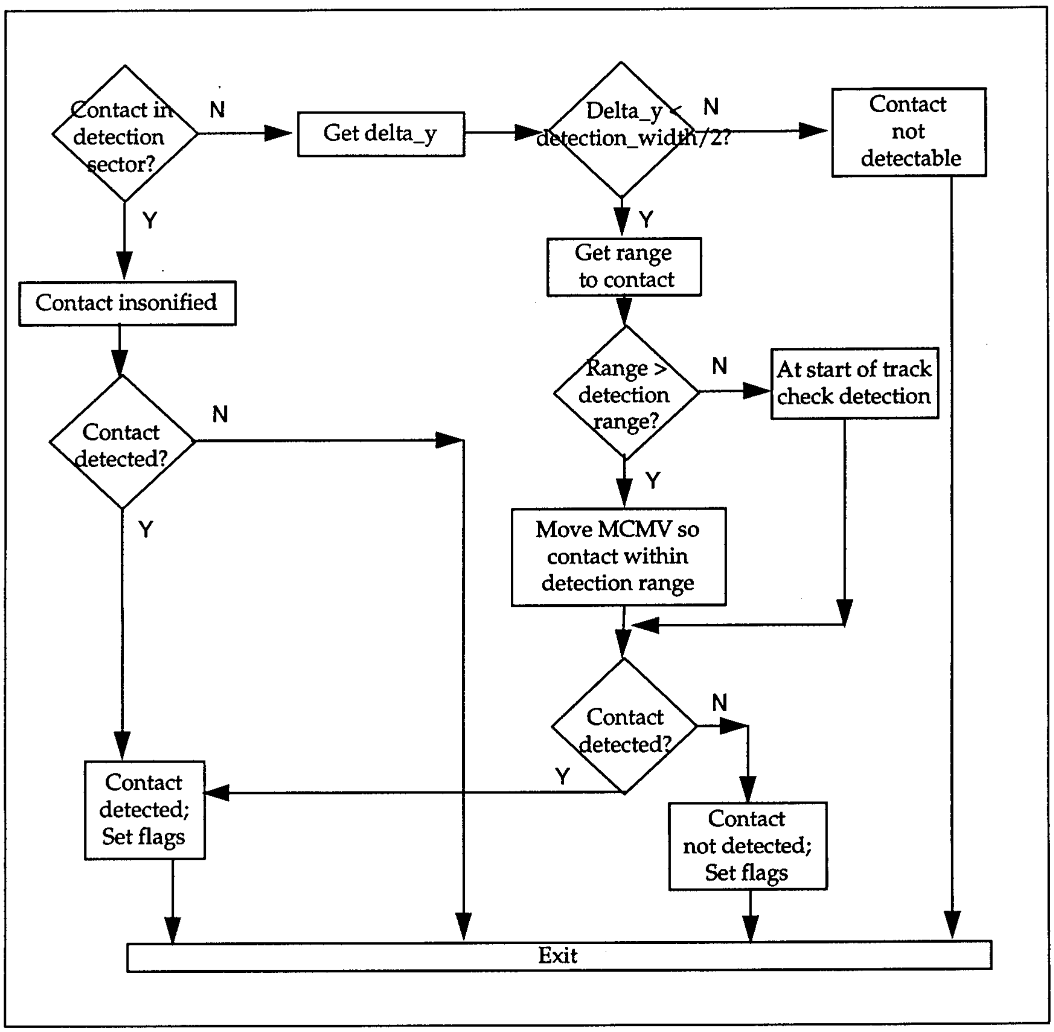

Figure C.3: Flowchart of detection subprocess using constant rectangular probabilities.

C.1.3 Classification of a Contact

In the model classification is a simpler process than detection. It is assumed that the MCMV manoeuvres to the best position to classify the object (Event 29) requiring a randomly-determined reaction time to do so. The contact is then classified as either a mine or non-mine after an appropriate reaction time (Event 4).

The classification process is shown in Figure C.4

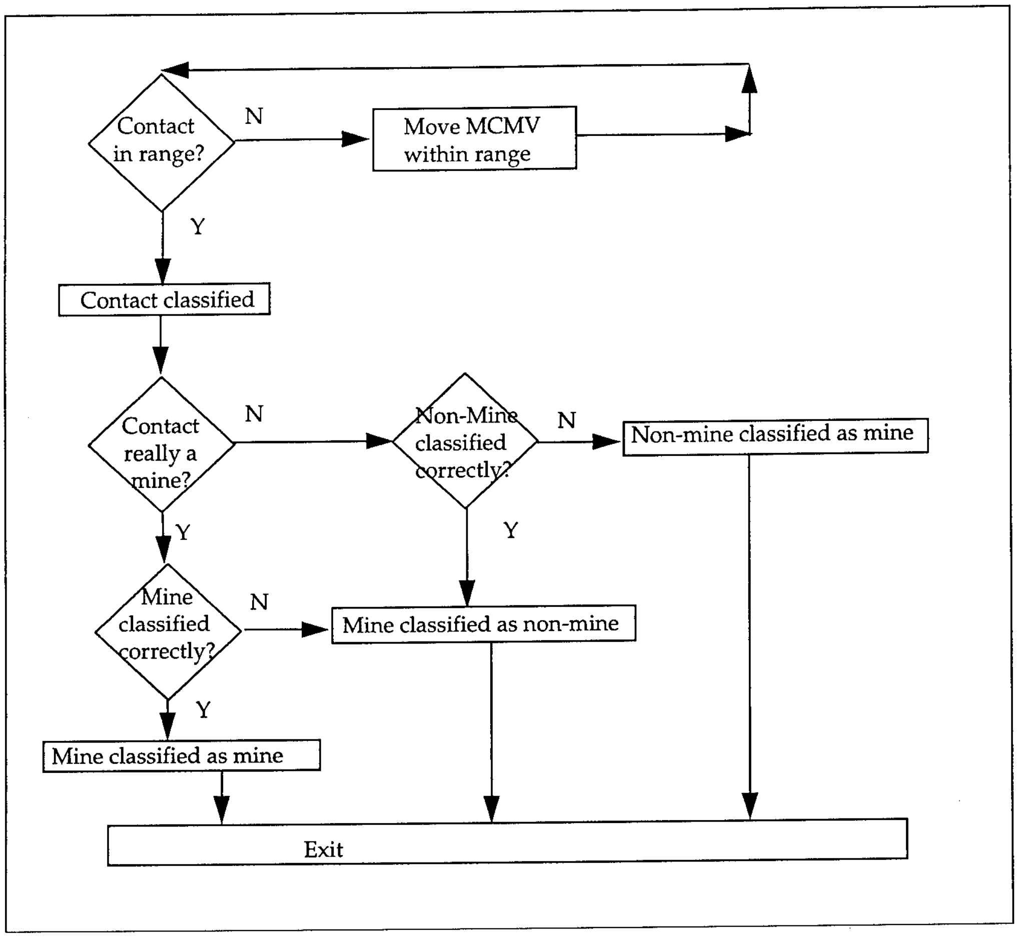

Figure C.4: Flowchart of contact classification subprocess

C.1.4 Investigation of a Possible Mine

When a contact has been identified as a possible mine the MCMV moves to the hover position (event 6), deploys the ROV (event 31) which relocates the contact (event 7) and makes an identification (event 8). If the contact is identified as a mine it is prosecuted by laying a mine disposal charge (event 9); otherwise the ROV is recovered to the MCMV (event 10). Note that if the object is really a non-mine but is identified incorrectly as a mine then it is also prosecuted incorrectly as a mine.

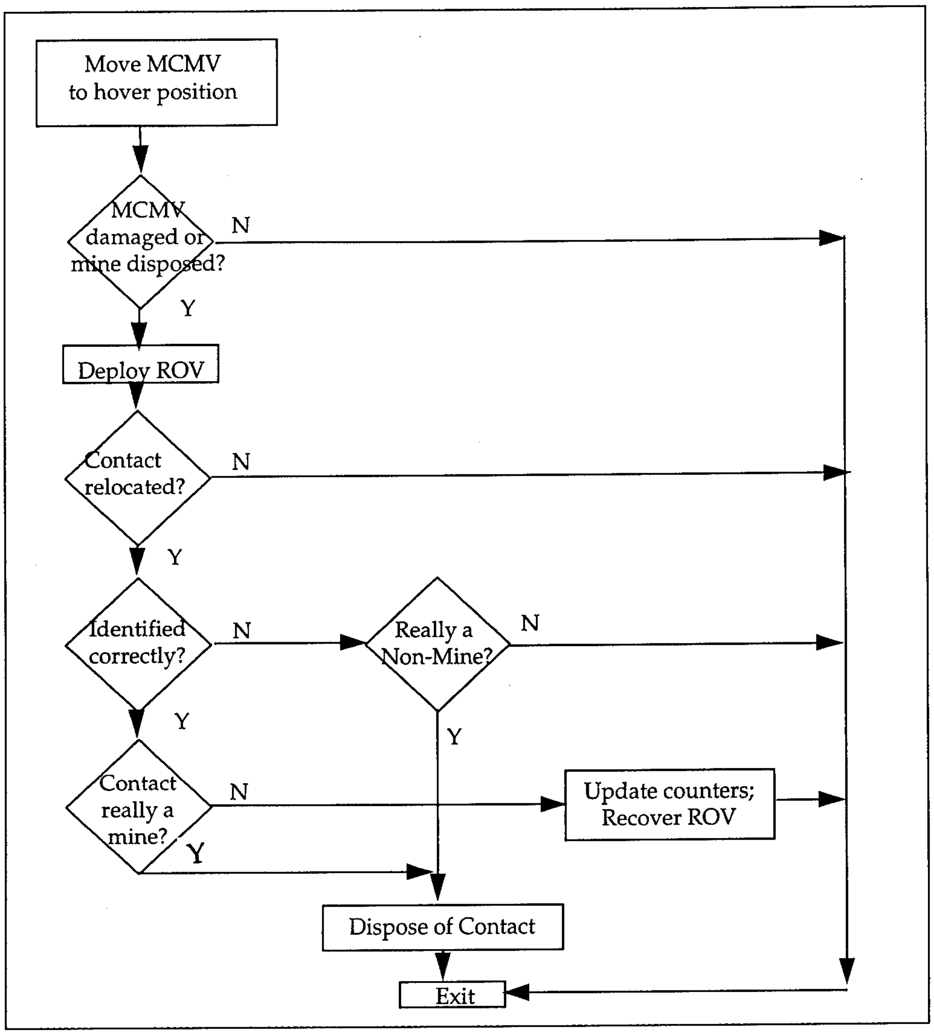

Figure C.5: Flowchart of contact investigation subprocess

C.1.5 Mine Prosecution

When a mine identification has been made (event 8), the ROV lays a mine disposal charge (event 9) and is then recovered to the MCMV (event 10). The MCMV is moved to the safe fire position and the disposal charge fired remotely after the arming delay has expired (event 11).

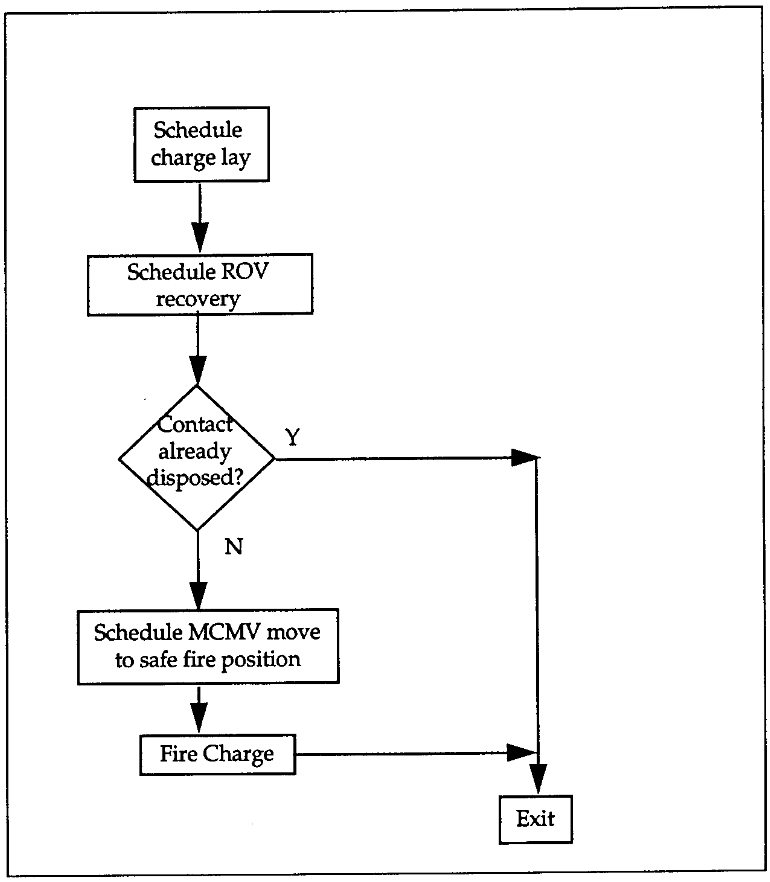

Figure C.6: Flowchart of contact prosecution subprocess

C.2 Next ROV Process (NR)

This process, whose flow chart is shown below as Figure C.7, is basically a queueing system which interacts with the battery charger process via the system variables (numbers of flat and charged batteries) and with the spare ROV (SPROV) process via a message (event 22 directly executes event 19 (decision on which ROV to use in the next ROV operation)). It implements a heuristic rule for deciding which ROV, i.e. the current SPROV or the current next ROV (NEROV), to use in the next ROV operation. This decision is made as soon as an ROV is recovered after an ROV operation, the NEROV then being in the state of waiting for a decision on the new NEROV (MD). The decision rule is as follows:

a. If the current SPROV does not have an installed battery, it becomes the new NEROV. This is a plausible rule because the current NEROV, which has just been recovered, will probably need to have its battery removed before its next operation, and the current SPROV has already had this done, and will probably be already undergoing turnaround; and

b. If the current SPROV has an installed battery, the new NEROV will be chosen as the one with the greatest battery life remaining. As both ROVs have installed batteries in this case, the rule is plausible. The current NEROV may need to have a new MDC installed, however this eventuality was not taken into account in formulating the rule.

Whether or not the current SPROV becomes the new NEROV and vice versa, the remainder of NR is concerned with the NEROV turnaround process. If the ROVs have been interchanged, and the new NEROV has a fully charged battery installed, it is possible for the NEROV to transition directly to the state of waiting for the next mine classification event (WME). Immediately after this event occurs, the MCMV enters the wait for NEROV (WRO) state and the assemble event 5 (ROV becomes available) is executed.

Because of the possibility that the ROVs have been interchanged, the state of the NEROV could be waiting for a charged battery (WRB2) or in turnaround (TA2), and this has to be checked before any further events are executed. If the NEROV is waiting for a battery, the number of charged batteries is checked and if positive event 23 (battery arrives) is executed, signifying the start of turnaround for the NEROV. Otherwise it remains in the wait state WRB2. If the NEROV is in state TA2, it remains in this state until the turnaround reaction-time is up and event 24 (ROV turnaround finishes) executes. The NEROV then has a fully charged battery and moves to state WME to await a mine classification event.

If the ROVs have not been interchanged, the NEROV may or may not have a flat battery installed, and this must be checked. If the NEROV has a flat battery installed, it must be removed, the pool of charged batteries decremented, and the pool of flat batteries in the battery charging system incremented. If the NEROV does not have a flat battery installed, it must be in state WRB2 waiting for a charged battery to arrive (event 23) and this event must be placed on the wait list. Event 23 generates an ROV turnaround time, moves NR into the TA2 state and schedules event 24. When event 24 executes, NR moves into state WME as already described.

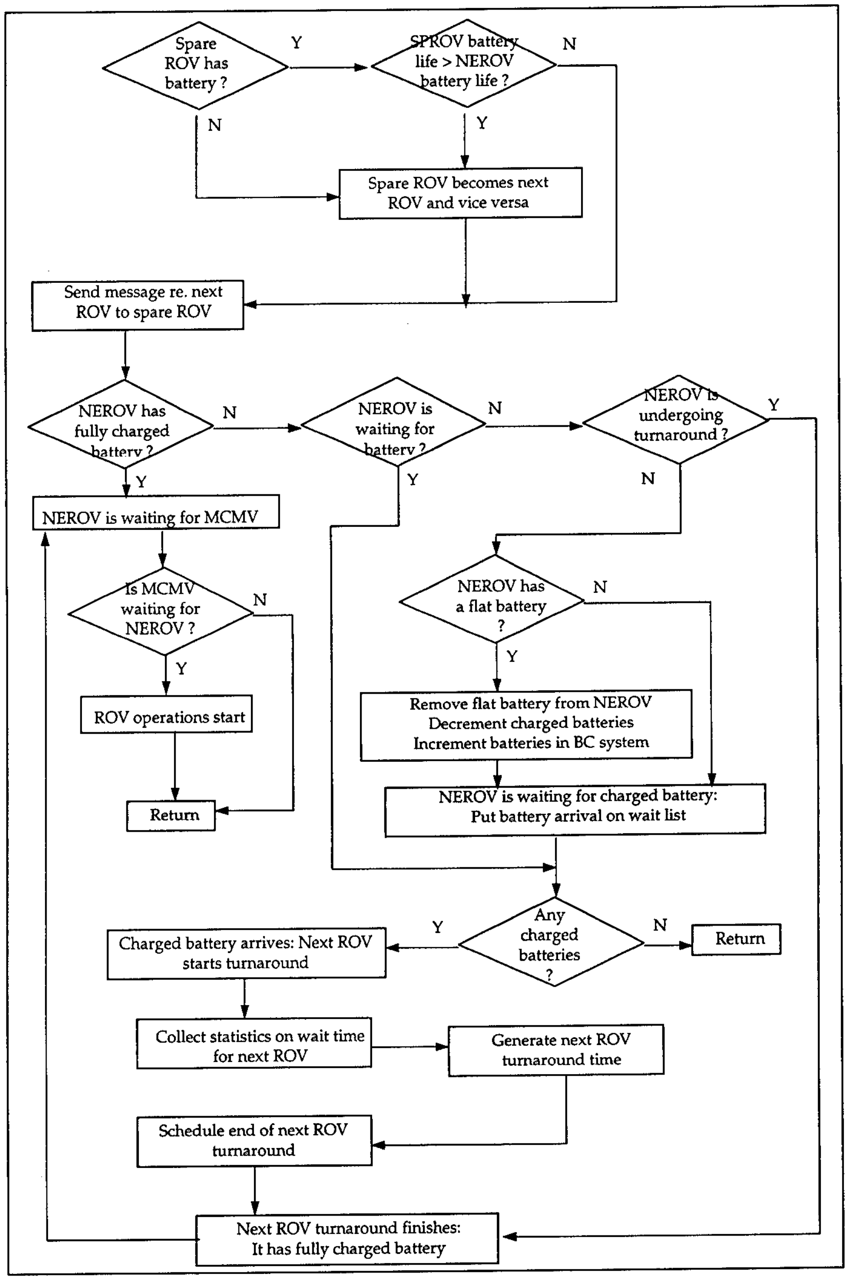

Figure C.7: Flowchart for Next ROV Process

C.3 Spare ROV Process (SR)

This process, whose flow chart is shown below as Figure C.8, is basically a queueing system which interacts with the battery charger process via the system variables (number of flat and charged batteries) and with the next ROV (NEROV) process via a message (event 22 directly executes event 19 (decision on which ROV to use in the next ROV operation)). The decision rule for deciding which ROV, i.e. the current spare ROV (SPROV) or the current NEROV, to use in the next ROV operation is described as part of the NEROV process. If the current SPROV becomes the new NEROV and vice versa, an "ROV interchanged" flag is set and checked as soon as the SPROV process begins. As event 19 is directly executed, the SPROV can be in any one of three states when it occurs: waiting for a decision on the next ROV (WDS), waiting for a replacement battery (WRB1) or in turnaround (TA1). If the ROVs have not been interchanged, the SPROV undergoes a self-transition, i.e. its state is unchanged.

If the ROVs have been interchanged, the new SPROV will have just completed an operation, and so will have a battery installed. This is tested, and if fully charged (remaining battery life above a threshold), the SPROV enters the wait state (WDS). If the installed battery is flat, it must be removed, the pool of charged batteries decremented, and the queue of flat batteries and the number of batteries in the battery charging system incremented. The SPROV then enters the wait state (WRB1) and puts a battery arrival (event 20) on the wait list. In this state the number of charged batteries is checked and if positive event 20 is executed, signifying the start of turnaround for the SPROV. Otherwise it remains in state WRB1. Event 20 generates an ROV turnaround time, moves SR into the TA1 state and schedules the finish of the SPROV turnaround (event 21). When event 21 executes, the state of the MCMV process is checked to determine whether SR becomes idle. If minehunting is finished (MCMV process in states return to port (RP) or wait for other processes to end (WCE)) SR enters its idle state (I4). A check is then made as to whether both battery chargers are idle, and if so the assemble event 25 (minehunting cycle ends) is executed immediately.

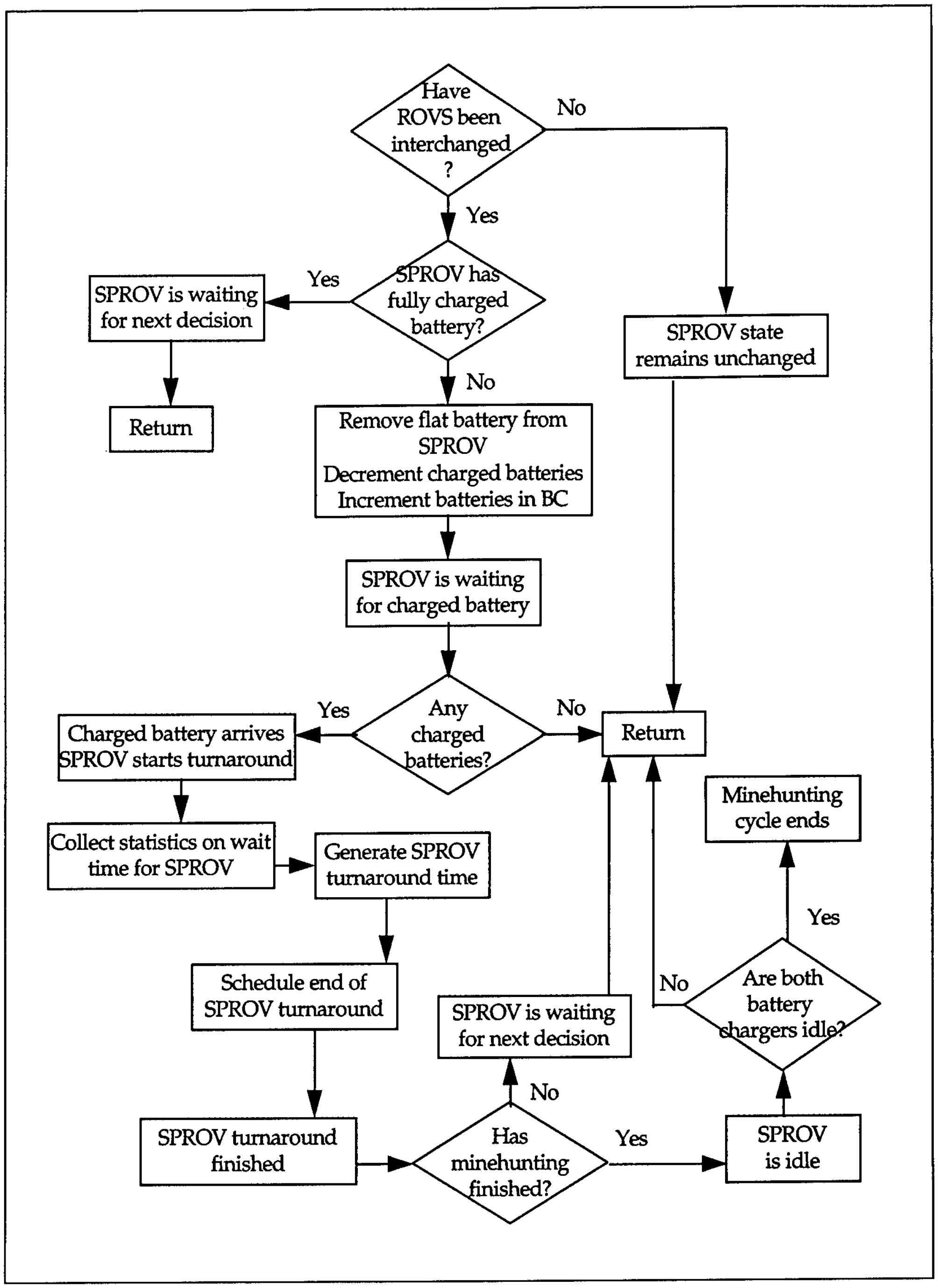

Figure C.8: Flowchart for Spare ROV Process

C.4 Battery Charger Process (BC)

This process, whose flow chart is shown below as Figure C.9, is a simple queueing system. The same process describes both battery chargers if there are two. If the BC is waiting for a battery to arrive (state (WFB)) the number of flat batteries in the queue is checked, and if positive event 17 (battery charger starts) is executed. This decrements the battery queue length, generates a time to charge the battery, moves BC to the charge battery (CB) state, and schedules event 18 (battery charging finishes). Event 18 is then executed after a reaction-time. This decrements the number of batteries in the battery charging system, increments the number of charged batteries and either schedules another event 18, leaving BC in state CB, if there is a queue of flat batteries; returns BC to state (WFB) and puts another event 17 on the wait list, if there are no flat batteries and minehunting has not finished (MCMV Process in states return to port (RP) or wait for other processes to end (WCE)); or puts BC in its idle state (I3) if there are no flat batteries and minehunting has finished. When BC enters its idle state, a test is made of whether the assemble event 25 (minehunting cycle ends) can be immediately executed. The conditions for this are that the Spare ROV Process (SR) is idle (state I4) and the other battery charger, if any, is not operating, i.e. either waiting or idle.

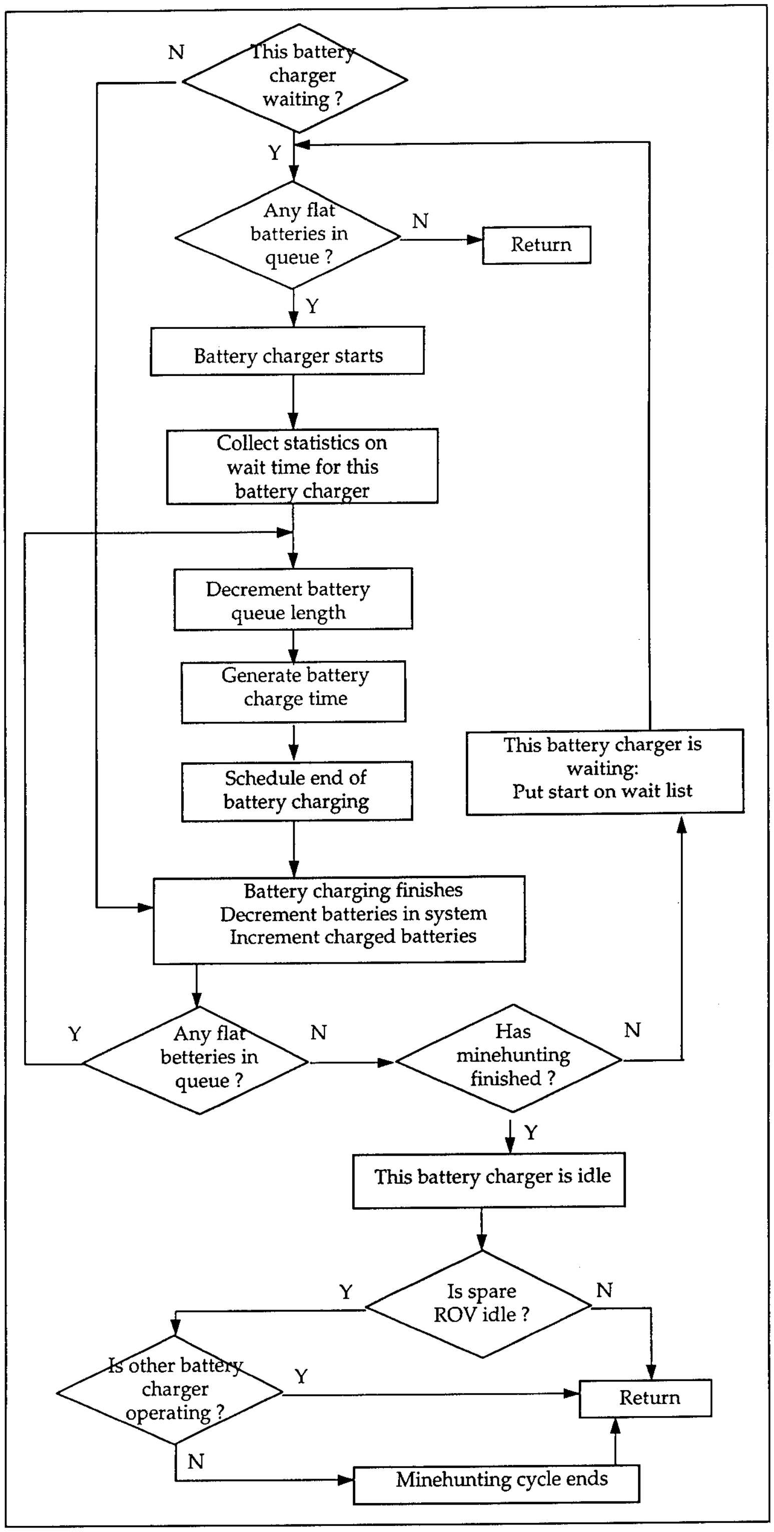

Figure C.9: *Flowchart for Battery Charger Process*

Annex D: Additional Output from MHUNT Model

This Annex contains details of the additional outputs that can be obtained from the MHUNT model: the event-state trace and the graphical file output. These are described in the following sections.

D.1 Event-State Trace

The event-state trace is an optional output from single replication runs of the simulation. An example of part of an event-state trace is shown below as Figure D1, with explanations of each of the different types of output given in boxes. Each event trace lists, from left to right, the time the event occurs, the event name, and the value of each event pointer element. All simultaneous events are listed, followed by a state trace, with abbreviated state names as shown on the state transition diagram, for that time. The main system variables are also listed after the state trace.

The event-state trace is useful for verifying that the program operates as specified by the directed graph, and for debugging. Once the model has been verified and validated, the program can be run in event-state trace mode to better understand the actual system operation.

BEGIN OPERATION FOR REPLICATION 1

ROV parameters:
number (1 or 2)
type (battery(B) or cable (C))
number of battery chargers (1 or 2)
total number of batteries (integer)

NO OF ROVS : 2 TYPE OF ROV : B
NO OF BATTERY CHARGERS : 2 NO OF BATTERIES : 3

time of event hr:min | name of event | event number | process number | duplicate number

0: .0 LEAVE FOR OP AREA EVTNUM= 1 PROC= 1 DUPL= 0

0: .0 TO WME

state trace at time 0
process 1: transit to operational area
process 5: wait for mine event

NCM = 0 NBATSE = 3 NBATQ = 0 NERONO = 1
SPRONO = 2 BATLRNE = 90.0 BATLRSP = 90.0
ITRACK = 0 JRUN = 0

system variables at time 0
no of contacts (mine): 0
no of serviceable batteries: 3
no of batteries in queue: 0
next ROV serial number: 1
spare ROV serial number: 2
next ROV battery life remaining: 90
spare ROV battery life remaining: 90
track # 0
run # (on track): 0

```
3:17.1  ARRIVE AT OP AREA          EVTNUM= 2  PROC= 1  DUPL= 0
3:17.1  START HUNTING ON TRACK      EVTNUM=26  PROC= 1  DUPL= 0
3:17.1  RESUME HUNTING ON TRACK     EVTNUM=27  PROC= 1  DUPL= 0
```

all events occurring at the same time

```
3:17.1  SC       WFB  WFB  WDS  WME

        NCM = 0 NBATSE = 3 NBATQ = 0 NERONO = 1
        SPRONO = 2 BATLRNE =  90.0 BATLRSP =  90.0
        ITRACK = 1 JRUN = 1
```

state trace at time 3 min 17.1 sec
process 1: search for contact
process 2: not operating
process 3: (duplicate 1) wait for battery
process 3: (duplicate 2) wait for battery
process 4: wait for a decision on next ROV
process 5: wait for a mine classification event

```
3:29.2  START CONTACT DETECTION     EVTNUM= 3  PROC= 1  DUPL= 0
3:29.2  SC       WFB  WFB  WDS  WME
        NCM = 0 NBATSE = 3 NBATQ = 0 NERONO = 1
        SPRONO = 2 BATLRNE =  90.0 BATLRSP =  90.0
        ITRACK = 1 JRUN = 1

3:30.9  END CONTACT DETECTION       EVTNUM=30  PROC= 1  DUPL= 0
3:30.9  CC       WFB  WFB  WDS  WME
        NCM = 0 NBATSE = 3 NBATQ = 0 NERONO = 1
        SPRONO = 2 BATLRNE =  90.0 BATLRSP =  90.0
        ITRACK = 1 JRUN = 1
```

Figure D1: *Part of Event-State Trace*

D.2: Graphical Output

The MHUNT model produces an output file consisting of information which graphically represents the events that occurred during a simulated minehunting operation. This output file is produced by the 'Write_Graphics_File' subroutine and contains the following information:

(1) Minefield data - dimensions of the field.

(2) Tactical data - track geometry and tactic-type.

(3) Mine and (4) non-mine data. These define the number, position and status of three parameters: detection, classification, and identification for each mine and non-mine.

(5) MCMV data. These define the total number of events and, for each MCMV event, the MCMV position recorded when each event occured.

(6) ROV data These define the total number of ROV events and, for each ROV event, the ROV position recorded when each event occurred.

Figure D.2 show an edited output file produced by the program.

This output file can be read into a Visual Basic program. This system uses Visual Basic's graphical capabilities to draw the minefield, place the mine and non-mines, and show the path of both the MCMV and the ROVs. The locations of the mines and non-mines can be indicated by a key set of symbols to reflect the detection, classification and identification of the mines and non-mines.

```
**** MINEFIELD DATA - Length, width, depth
  20386.000000    1000.000000    30.000000

**** TACTICAL DATA ****
       1      ##### No. of tracks
   500.000000   0.000000E+00    1000.000000        0
 MINIMUM EFFORT
NO

***** MINE DATA ****
       3        ##### No. of mines
No.            xpos         ypos         detect       classif.      identif.

1              15746.39     979.79       T            M             M
2              15520.89     721.77       T            M             M
3              17055.83     980.93       T            M             M

***** NON-MINE DATA ****
      10      ##### No. of non-mines
No.            xpos         ypos         detect       classif.      identif.

1              476.44       949.12       T            M             N
2              8242.33      309.21       T            N             U
3              10806.32     641.15       T            N             U
4              16543.43     56.49        F            U             U
5              18585.88     294.12       T            N             U
6              10828.41     941.00       T            N             U
7              2487.79      156.96       T            N             U
8              11403.32     53.96        T            N             U
9              8984.45      179.53       T            N             U
10             9602.63      120.32       T            N             U
```

```
**** MCMV DATA ****
    170      #### No of MCMV events
Event no    xpos        ypos
  1        1.69       506.02
  2        5.64       490.70
  3        3.24       495.85
  4      296.82        778.51
 ---
 ---
 ---
 163    18470.47      486.34
 164    19764.84      123.13
 165    19753.72      505.52
 166    19760.42      509.33
 167    20115.98      583.30
 168    20117.77      499.21
 169    20113.49      500.81
 170    20386.67      493.02

**** ROV DATA ****
     10      #### No. of ROV events
ROV Event no          xpos          ypos    MCMV Event no.
     1               408.66        877.71          5
     2               476.44        949.12          5
     3               4129.56        875.38         42
     4               4197.00       949.71         42
     5               15430.25      714.27         124
     6               15520.89      721.77         124
     7                15665.32     917.40         129
     8                15746.39     979.79         129
     9                17030.26     887.88         149
     10              17055.83      980.93         149
```

Figure D.2: An output file produced by the 'Write_Graphics_File' subroutine'.

Annex E: Symbols and Abbreviations

Symbol/Abbreviation	Meaning
A	Mine Actuation Width
AMRL	Aeronautical and Maritime Research Laboratory
B	Mine Actuation Probability
B_d	Probability of Damage by Mine
C	Channel Width
CL	Mean Clearance Level
cl_i	Clearance Level (Replication i)
d	Track Spacing
δ	MCMV's Hover Distance
D	Detection Width
d_{all}	Total Number of Mines Disposed (all replications)
d_i	Number of Mines Disposed (Replication i)
DLL	Dynamic Link Library
η	Edge Reduction Factor
J	Number of Runs per Track
L	Track Length
M	Number of Mines in Field
MCM	Mine Countermeasures
MCMV	Mine Countermeasures Vessel
MCS	Minefield Clearance Simulation
MDC	Mine Disposal Charge
MHC	Mine Hunter Coastal
MOE	Measure of Effectiveness
MWSC	Mine Warfare Systems Centre
N	Number of Tracks
NAG	Numerical Algorithms Group
n_{all}	Total Number of Mines in Field (all replications)
n_i	Number of Mines in Field (Replication i)
θ	Sector Angle
R	Number of Replications
RAN	Royal Australian Navy
ROV	Remotely Operated Vehicle
σ	Navigation Error
STD	State Transition Diagram
TMSS	Total Mine Simulation System
T_p	Mine Prosecution Time
v	Mean Speed of Advance (of MCMV)

User Guide and Specification for Discrete-Event Minehunting
Simulation Model MHUNT

R.B. Watson, P.J. Ryan and B. Gilmartin

(DSTO-TN-0003)

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User guide and specification for discrete-event minehunting simulation model MHUNT

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ABSTRACT

Minehunting is a complex process involving detection and classification of contacts using sonar and the subsequent identification and disposal of mines generally using a remotely operated underwater vehicle (ROV). However, making suitable assumptions, minehunting can be approximated by a series of connected events and thus made amenable to modelling using the technique of discrete-event simulation. In this report, a discrete-event minehunting simulation model is described together with instructions for its operation. The model can be applied to evaluate the effectiveness of minehunting systems for a given operational scenario and also to investigate new concepts.