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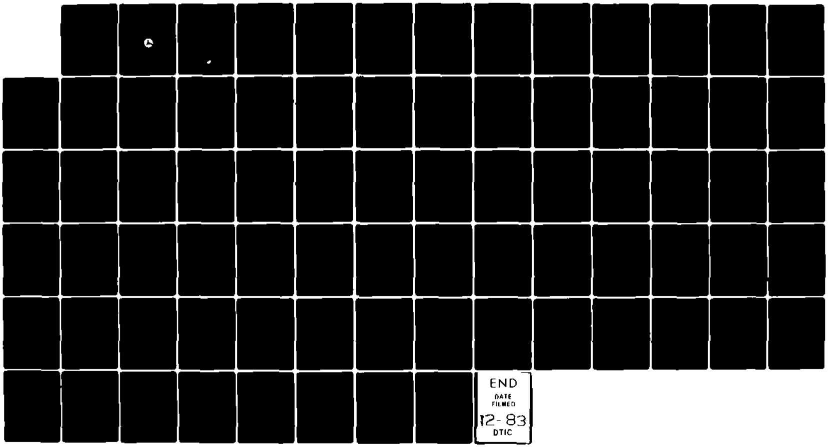

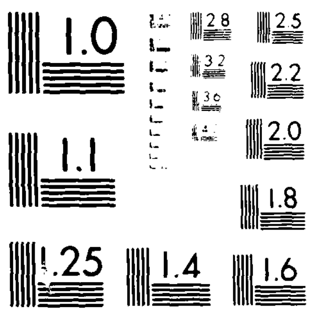

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MEASURES OF EFFECTIVENESS FOR MARINE VEHICLES FOR COAST GUARD LAW ENFORCEMENT MISSIONS

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16. Abstract

This report describes an analytical model developed to evaluate the measures of effectiveness of marine vehicles in performing law enforcement missions. An extensive input section enables the model to be sensitive to craft characteristics, environmental factors, tactical decisions, and policy decisions as well as changes in vessel traffic. The model computes a number of MOEs including interdiction rate, tonnage seized, and number of smugglers seized. Extensive output is generated by the model including histograms that present the average times devoted to the various phases of a law enforcement mission and histograms that indicate overload.

The model output, especially the histograms, indicate areas in which changes can be made that will improve the MOEs. This information enables the model to be used for sensitivity analysis. An example of a completed run is presented to demonstrate how the model is used.

Most of the components of the model have been coded into BASIC and are running on an HP-9845 desktop computer. These algorithms were used to calculate the baseline performance for the sample run and also to compute the sensitivity of the MOE to a range of changes in craft characteristics, environment, and tactics.

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METRIC CONVERSION FACTORS

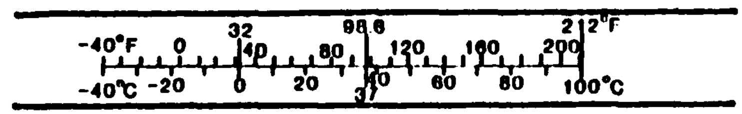
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The Advanced Marine Vehicle (AMV) program is administered by the Office of Research and Development (G-DMT-2) in Coast Guard Headquarters. One of the objectives of the AMV program is to assess the operational performance of various advanced concepts such as hydrofoils and surface effect ships. This report describes an analytical model that was developed to compute measures of effectiveness (MOEs) that can be used to evaluate the performance of an advanced marine vehicle in a law enforcement patrol.

The mathematical model described in this report is the result of a joint effort between personnel from the Coast Guard Research and Development Center in Groton, Connecticut, and Analysis & Technology, Inc., in North Stonington, Connecticut. Under this contract (DTCG39-82-C-80349), preliminary measures of effectiveness were previously developed.

The personnel who have been associated to various degrees with this phase of the project are:

Analysis & Technology -- J. Arrigan and H. Sheets
Advanced Technology -- L. Tedeschi
Coast Guard R&D Center -- C. Pritchett and D. Motherway
CG Office of R&D -- LCDR J. Tozzi (G-DMT-2)
Office of Operations -- LT R. Lang (G-OLE-1),
LT B. Hunter (G-OLE-3)

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SECTION 1
INTRODUCTION

1.1 PURPOSE

The purpose of this report is to describe an analytical model developed to compute the measures of effectiveness (MOEs) of advanced marine vehicles (AMVs) and other craft in performing a law enforcement mission. The report also discusses applications of the model and explains some of the various ways that environment, tactics, and vessel characteristics are incorporated into the model and analysis.

1.2 BACKGROUND

The advanced marine vehicle program is composed of technical and operational evaluations (TECHEVAL/OPEVAL) and operations research and operations analysis (OR/OA). The TECHEVAL/OPEVAL is primarily concerned with the engineering and operational characteristics of AMVs. This information is obtained through test and evaluation of existing vessels, ship model tests, and analytic and engineering studies. Much of this information will make up the AMV data base in the Office of R&D.

The OR/OA portion of the AMV project is structured to answer questions relating to operational performance and ownership of AMVs. Items such as life-cycle cost, the required number of vessels, maintenance, reliability, mission performance, and the ranking of overall performance for different vessels within the expected mix of missions are included in the OR/OA portion of the project.

Law enforcement, and anti-drug smuggling patrols in particular, is an important element in the mix of missions envisioned for an AMV. The MOE traditionally used by Coast Guard Headquarters (G-OLE-1) to measure performance in drug operations is the interdiction rate, which is defined as the tonnage of drugs intercepted divided by the tonnage of drugs attempting passage. The interdiction rate can be computed locally or globally, i.e., for a particular region or for all waterborne drug traffic. It must be computed as a function of on-station time or total mission time.

The interdiction rate is related to the economic gain of the drug traffickers. There is some value of global interdiction rate that, if reached, will result in "zero net profit" to the smugglers. It is postulated that if there were no potential profit, the drug runners would discontinue their operation at sea.

The initial effort to develop this measure of effectiveness analytically was done in 1982. The resulting MOE was a single equation that had to be loaded with several parameters (see reference 4). These included the rate at which vessel traffic enters the area, the probability of detection, cutter speed, distances, and boarding times. Also included were parameters affecting boarding rates, the fraction of smugglers, and level of suspicion. Although this MOE included a large number of operational inputs, it was clear that additional inputs and output were desirable. The areas that required additional attention were:

1. Effect of seakeeping on craft and crew performance,

2. Sensitivity of the MOE to operational decisions, and

3. Detailed output of the various phases of a patrol that provides insight into the operational patrol.

Although interdiction rate is presently used by G-OLE-1 to measure performance in drug operations, other groups have expressed interest in additional MOEs such as tonnage seized and the number of seizures. Therefore, the present model provides not only the interdiction rate as the MOE for a patrol, but extensive additional information such as seizure rate, average times to perform individual tasks, and total time spent on the different phases of the enforcement of laws and treaties (ELT) patrol. These data enable the analyst to compute off-line a number of additional MOEs that are of interest.

1.3 LAW ENFORCEMENT PATROL DESCRIPTION/OVERVIEW

Since Coast Guard law enforcement patrols for drugs are a recent evolution, MOEs are needed to evaluate performance. In perspective, these patrols are only an extension of what the Coast Guard has been doing since it was founded in 1790, i.e., looking for smugglers. The objective then was to catch smugglers who were not paying duties on the goods brought into the country. Now the objective is to prevent cargos of marijuana from being brought into the country.

A law enforcement patrol is generally planned to capitalize upon the geography of the region. Instead of patrolling in the open ocean, the cutter operates in choke points that the traffic must penetrate. This improves the probability of detecting a vessel. There are various searching patterns and operating concepts that may be chosen depending upon the particulars of the region. In addition to the patrolling function, the cutter may be directed to a location in response to vessel sightings by ships or planes or to intelligence reports.

Four aspects of the patrol are of specific interest. These are region of operation, vessel traffic, Coast Guard cutter, and operating policy.

Region of operation concerns the geography of the problem such as the size of the choke point, the locations of the refueling point, and home port or other operating bases. Also included are navigational considerations such as water depth and islands, and weather effects such as sea state and visibility.

Vessel traffic operating in the region is divided into categories of nationality, tonnage, and speed. The percent of vessels in each category that are smugglers is prescribed. Traffic distributions are defined by the arrival rate and entry points of each category of vessels that enter the patrol area.

Coast Guard cutter, for modeling purposes, is described by vessel speed as a function of sea state, fuel consumption as a function of speed, endurance, seakeeping effects on crew and equipment, weather limitations, and the electronic sensors and communications systems that are carried on board.

Operating policy includes tactical factors that the Coast Guard controls such as search pattern, speed selection, boarding policy, the use of prize crews, type of escort, and refueling policy. All of these tactics require a decision or choice by various people in the Coast Guard chain of command. This is unlike the other three categories in which most factors describe the state of nature. The drug trafficker chooses the region of operation and tries to blend into the vessel traffic in the area. The particular Coast Guard cutter is determined by procurement decisions.

1.4 OBJECTIVE

The objective of this report is to describe an analytical model that can be used to evaluate the performance of Coast Guard craft on an ELT mission. The model developed for the AMV program must specifically test the sensitivity of the MOE to craft characteristics such as seakeeping and speed. Seakeeping affects both the ability of the crew to perform tasks such as monitoring radar and also the length of time the craft can perform the mission. The model, therefore, must incorporate human factors in a way that MOEs are sensitive to people performance. Speed, endurance, displacement, and close-in maneuverability must also be incorporated into the model. The inputs, outputs, and logic of the model are described in section 2 of this report.

The Coast Guard is presently developing a new ELT data base which can be used for input to the model in the future. Although the present model was developed and checked using only hypothetical data, this report describes the data needed to load the model and also the format in which it must be collected. The report also explains the manner in which factors such as sea state, weather, seakeeping, and tactical decisions are incorporated into the model. The report also discusses possible scenarios in which the model can be used and techniques for using the model to perform sensitivity analysis.

SECTION 2
TECHNICAL APPROACH

2.1 ANALYSIS OVERVIEW

The analysis procedure developed for use with the ELT model is presented in figure 2-1. A brief overview is provided in the following paragraphs.

After determining the issues to be analyzed, choosing a cutter, and determining infiltration rate, an appropriate scenario must be developed. The scenario determines the operational and environmental situations in which evaluations are to be made. The number of possible combinations of opposing vessels, tactical rules, and other factors is practically unlimited. Obviously, the more factors that are introduced, the more difficult the output is to analyze. The scenarios that are selected must represent a balance between operational realism, modeling limitations, time constraints, and ease of interpretation.

A typical scenario is shown in figure 2-2. A Coast Guard cutter is patrolling a choke point between two islands. It is assumed that smugglers are crossing the barrier only in the direction toward the United States. The tasks of the cutter are to detect, close, board, and seize smugglers.

The law enforcement patrol is modeled as being composed of six distinct phases:

1. Transit to and from station,

2. Search until a vessel is detected,

3. Intercept or close the vessel,

    Close -- close to visual range
    Alongside -- come alongside

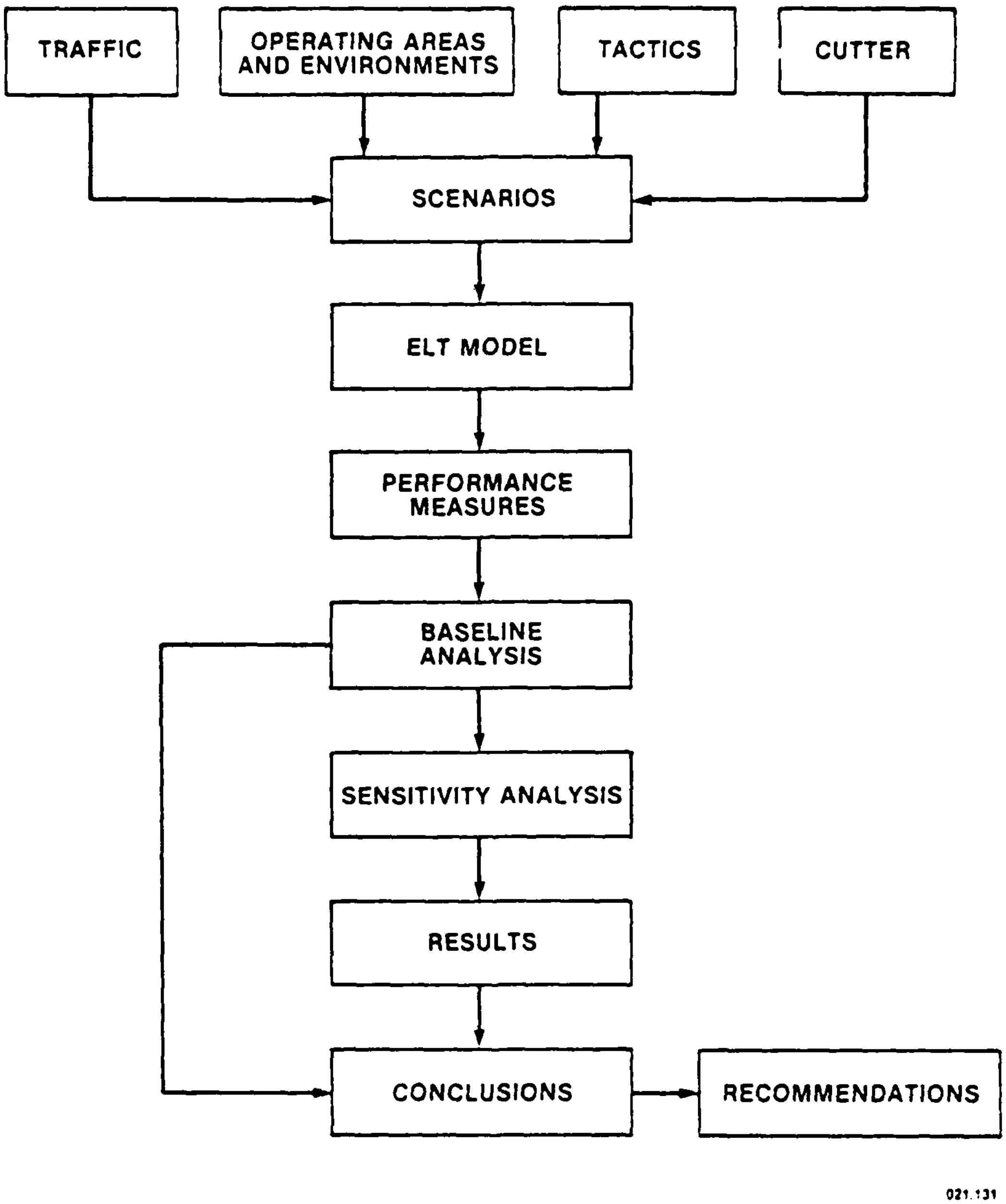

Figure 2-1. Analysis Overview

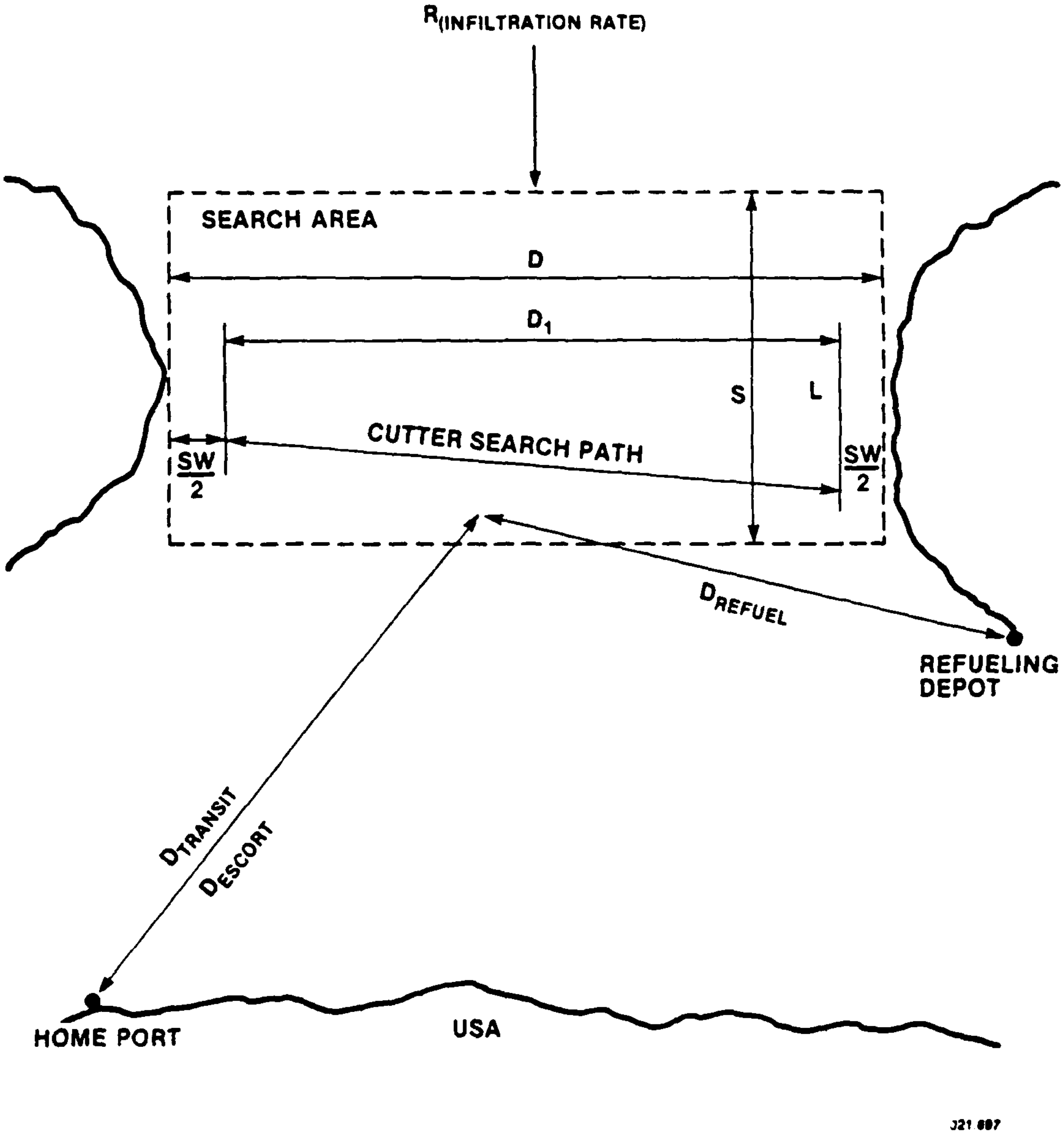

Figure 2-2. Typical ELT Scenario

4. Board the vessel,

5. Seize and escort the vessel if it is a smuggler, and

6. Divert (refuel, search and rescue (SAR), night, weather, etc.).

After transitting to station, the cutter begins searching. Once a vessel is detected, the decision is made about closing for a visual inspection. The decision may be not to close, for instance, if the contact is determined to be a very large vessel (e.g., warship) or a vessel that is faster than the cutter.

The intercept phase is divided into two parts. The cutter will close first for a visual inspection. At this time, the cutter may come alongside it or can break off the intercept and revert to search. Once alongside, the decision to board or continue to search is made. A vessel that is boarded is seized and escorted if contraband is found; otherwise, the cutter reverts to searching. After a vessel is escorted to a drop-off point, the cutter returns to station and begins searching. Diversions to refuel, for bad weather, etc., occur as necessary.

Once on-station, the cutter attempts to complete a detect-intercept-board-escort cycle. Most detections, closings, and boardings do not warrant continued prosecution. Consequently, the cutter goes back to searching. The ELT measures of effectiveness are basically a function of the number of smugglers a cutter can seize during its on-scene time. The computation of the MOE essentially requires determining, for a given set of inputs, the amount of time the cutter spends searching, closing, and boarding before it finds a smuggler that it escorts to the hand-off point. Figure 2-3 is a graph of one complete on-scene cycle. This shows that the cutter, after detecting a vessel, can either close the vessel or continue searching. Likewise, after each subsequent phase, the cutter can continue prosecuting a contact or revert to searching. The cutter always reverts to searching after escorting a smuggler in this model.

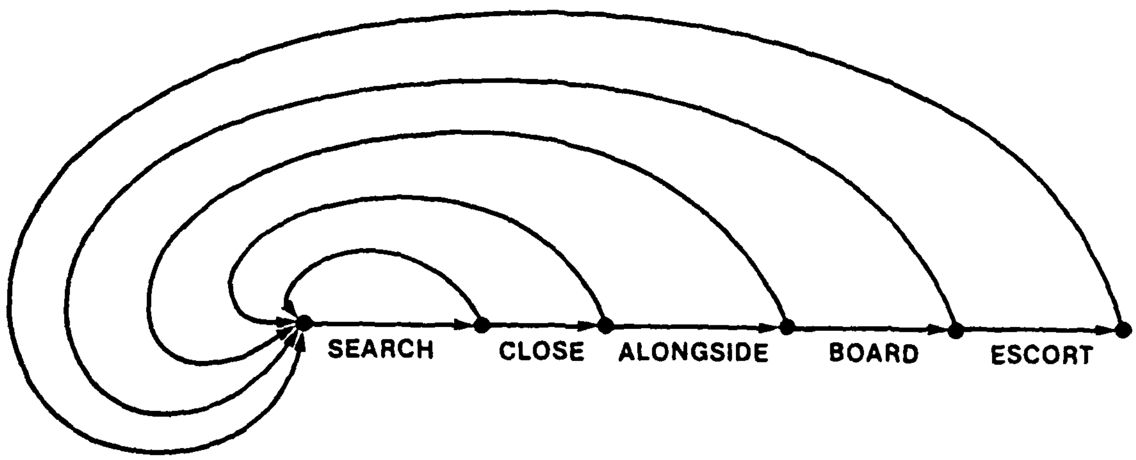

Figure 2-3. Network Depicting On-Scene ELT Cycle

Knowing the amount of time required to complete one cycle and the infiltration rate, it is possible to compute the on-scene interdiction rate. Also, knowing the time required to transit to station, the total mission time, and the time diverted to other tasks, it is possible to compute the number of cycles a cutter can complete during a mission. This information enables the analyst to determine other MOEs such as tonnage seized, number of seizures, and the interdiction rate for the mission.

2.2 INPUTS

Inputs that describe the traffic, cutter, geographic area, decision policy, and average times to perform such tasks as obtaining the statement of no objection (SONO) are discussed in this section. The sample run in appendix B contains a complete listing of the inputs and outputs of the model with the hypothetical values used for the sample run.

2.2.1 Traffic

Traffic in the search area is divided into 12 categories for this presentation. The number of categories can be either expanded or contracted very easily. Increasing the number of categories, however, greatly increases the task of collecting data. Traffic is broken down by two factors: craft type and craft flag. Table 2-1 is a sample traffic breakdown using five types of craft.

Table 2-1. Sample Traffice Breakdown

FLAG	VESSEL TYPE				
	VERY LARGE	MERCHANT	FISHING	PLEASURE	VERY FAST
U.S.					
HIGH INTEREST FOREIGN					
ALL OTHER FOREIGN					

The following data is needed for each category of traffic:

1. Number entering patrol area per day,
2. Percent that are smugglers,
3. Average tons of marijuana on a smuggler,
4. Average transit speed,
5. Average evasion speed,
6. Percent of vessels that are of special interest to the Coast Guard,
7. Average time to seize a smuggler, and
8. Average time to obtain a SONO.

2.2.2 Cutter

The model also requires a number of cutter inputs such as:

1. Transit speed,
2. Search speed,
3. Intercept speed,
4. Sweep width,
5. Average time to board a vessel given ready to board,
6. Average time to search a boarded vessel,
7. Average time to refuel given at refueling station, and
8. Average time to release a vessel at the hand-off point.

Cutter inputs directly or indirectly model cutter characteristics. The three speeds are fairly straightforward. Since sweep width generally assumes radar detection, sweep width is a function of mast height and sea state. In heavy seas, radar can be degraded by ship motion.

The seakeeping characteristics of the vessel additionally affect the sweep width since fatigue and seasickness affect the ability of the operator to perform his task. Sweep width is entered as the expected average sweep width considering all the aforementioned factors.

The average time required to board a vessel is a function of the cutter's close-in maneuverability and the need to launch a small boat. The average time to search a boarded vessel may be a function of craft characteristics if the displacement of the cutter limits crew size and, thus, the size of the boarding party. Likewise, the average time to release the vessel and process paperwork could depend on crew size. Leaving a prize crew on a smuggler could significantly reduce the average release time. Average time to refuel at the refueling station is a function of craft characteristics, but is probably not a driving factor compared to the transit time to the refueling point.

2.2.3 Geographic Area

Figure 2-2 illustrated a typical ELT patrol area. The necessary inputs are:

1. Infiltration rate,
2. Distance across patrol area,
3. Length or depth of the patrol area,
4. Distance from home port to patrol area,
5. Distance smuggler must be escorted from the patrol area, and
6. Distance from patrol area to refueling location.

2.2.4 Tactics and Policy Decisions

Three search tactics are available to the ELT model: random search, linear barrier patrol, and crossover barrier. Random search assumes the least information about the smuggler's course and destination. The two barrier searches assume that smugglers will attempt ˛ cross a barrier, for instance, between two islands. If the cutter has a significant speed advantage over the traffic of interest, then the crossover barrier is the most effective search tactic.

Most other decisions are made in reference to a type of vessel. These decisions are modeled as the probability that the cutter will make a decision to continue to prosecute a specific type of vessel. The decisions are modeled as:

1. The probability the cutter will close a vessel of particular size and speed (given detection),

2. The probability the cutter will bring the vessel alongside (given visual contact),

3. The probability the cutter will board the vessel (given that it is of special interest),

4. The probability the cutter will board the vessel (given that it is not of special interest), and

5. Total mission time.

2.3 OUTPUT

Three classes of output are generated by the ELT model:

1. Performance measures (MOEs),

2. Allocation of effort (number of tasks, time), and

3. Logistics (refueling, transits).

2.3.1 Performance Measures

The primary output of the ELT model is the interdiction rate, which is defined as:

$$I = \frac{\text{Tons seized}}{\text{Tons shipped/hour * number of hours}} .$$

The key to the interdiction rate is computing the average time required to complete one search-intercept-board-escort cycle. The model computes the average tons of contraband found on a smuggler and the number of hours required to seize one smuggler. From these factors the on-scene interdiction rate is computed, that is, the percentage of tonnage that is seized while the cutter is on-scene performing the ELT mission.

Knowing the average time required for one seizure, it is possible to compute the number of seizures that can be made during a mission. Including transit and refueling as well as other diversion times (SAR, weather, darkness, etc.) in the interdiction rate computations, it is possible to compute mission interdiction rate. This is the interdiction rate for the patrol from the time the cutter left home port until it returned. Since different classes of Coast Guard vessels require significantly different amounts of time in-port between missions, this port time has an effect upon the long-term interdiction rate. Building a scenario in which a number of crafts patrol an area over a period of time, it is possible to use the model to compute measures of effectiveness for the individual crafts and then to use these results to compute an overall interdiction rate.

If the cutter is deployed on a long patrol, conditions can change during the patrol, specifically weather, traffic density, and the percent of time the cutter is diverted to other missions. The model can be used to compute the interdiction rate for a cycle performed under a variety of conditions. An overall mission interdiction rate is then computed as a weighted average using the different interdiction rates and the percent of the mission time pertinent to each rate.

2.3.2 Allocation of Effort

Although the interdiction rate is the primary measure of effectiveness, the model computes a number of other factors that are helpful in analyzing the ELT mission. The first set of outputs is the average time required to perform an individual phase of the ELT operation once, and also the probability that the cutter will continue to prosecute a contact at each phase of the cycle. These outputs are:

1. Average time to transit to the patrol area,
2. Average time to detect a vessel,
3. Average time to close a contact to visual range,
4. Average time to bring a vessel alongside,
5. Average time to board a vessel,
6. Average time to escort a smuggler and return to station,
7. Average time to divert to refuel,
8. Probability that the cutter will close a vessel it detects,
9. Probability that the cutter will bring a visual contact alongside,
10. Probability that the cutter will board a vessel brought alongside, and
11. Probability that the cutter will seize the vessel (i.e., find contraband).

Of considerable interest in analyzing an ELT patrol is the number of times a cutter has to detect, close, and board before it finds a smuggler. Also, the total amount of time expended on each of these phases is of interest, especially in terms of optimizing the ELT operation. These outputs are:

1. Number of vessels detected in one cycle,

2. Number of vessels closed in one cycle,

3. Number of vessels brought alongside in one cycle,

4. Number of vessels boarded in one cycle,

5. Number of vessels seized in one cycle (always 1),

6. Time spent searching during one cycle,

7. Time spent closing during one cycle,

8. Time spent coming alongside during one cycle,

9. Time spend boarding during one cycle, and

10. Time spent escorting during one cycle.

These data are presented in histogram format.

Although the phases of the ELT mission are independent, it is possible for the cutter to detect traffic during all phases of an ELT operation. Computing and plotting the number of detections that occur while the cutter is closing, boarding, and escorting give an indication of saturation since the cutter cannot prosecute any of these contacts. This output is presented in histogram format. The equations used to compute the output are described in appendix A. An example of all output is included in appendix B.

2.3.3 Logistics

The ELT model also generates logistic data:

1. Number of hours transiting to station, and

2. Number of refuelings needed to complete one seizure.

2.4 SENSITIVITY ANALYSIS

The classical operations research techniques for optimizing a procedure cannot easily be applied to the ELT mission. Although very little contraband may be found when boarding a particular type of vessel, the Coast Guard, for various reasons, may want to continue to board this type of vessel. Traditional OR optimization techniques would advise the Coast Guard against continuing this practice. Likewise, the amount of time consumed waiting for the SONO might suggest that the Coast Guard concentrate on U.S. vessels as a way to increase the interdiction rate. This would only drive contraband to foreign ships. The optimization problem is also confounded by the fact that smugglers often can change tactics in response to tactical changes by the Coast Guard. Constant analysis is needed to enable the Coast Guard to find these changes.

The extensive output of the model suggests a feasible approach to sensitivity analysis and optimization. The printed output and especially the histograms identify phases of the mission in which large amounts of time are consumed. Knowing the time required to perform each phase of the mission and the number of times each phase has to be performed to effect one seizure, the analyst can identify areas in which time can be reduced and interdiction rate improved. An example of sensitivity analysis is included with the sample run in appendix B.

SECTION 3
APPLICATIONS

The extensive inputs into the ELT model enable it to be used in a variety of analytical applications, specifically, analysis of advanced marine vehicles, tactics, and policy decisions in various scenarios and environments.

3.1 ADVANCED MARINE VEHICLES DESIGN/EVALUATION

Craft characteristics such as speed, fuel capacity, and endurance are directly modeled since they are inputs to the model. Different ship concepts can be incorporated into the model by varying ship characteristics. For example, seakeeping is modeled with a speed sea-state relationship which shows voluntary and involuntary speed reduction. It is also modeled indirectly by its effect on detection systems, sweep width, and crew fatigue. The effect of changing vessel characteristics can be seen by comparing model outputs from one run to another.

3.2 TACTICS

The model allows the user to see the effect of changing search tactics such as search pattern or choice of speed. More complex tactical issues can be addressed such as using one vessel to search, intercept, and board, and a second one only to escort. This would involve running the model several times and fitting the different runs together to accurately fit the given situation. This tactic can then be compared with a vessel that performs all phases of the mission.

The use of intelligence can be modeled by changing the probability inputs so that the cutter concentrates on vessels of very high interest. If intelligence is old, the area of uncertainty (AOU) and traffic density could be sufficiently large that the cutter has to detect and close a number of vessels before locating the vessel of interest.

3.3 POLICY DECISIONS

Policy decisions have a strong effect on ELT MOEs. Optimizing seizure rate does not necessarily optimize interdiction rate in terms of tonnage since one significantly large seizure may involve more contraband than a number of smaller seizures. The ELT model can compute measures of effectiveness for a number of policy decisions such as concentrating on a particular class or nationality of vessel, or of boarding only vessels that have a high probability of being smugglers. The model can also be used to answer a number of questions such as "what if the Coast Guard concentrates on boarding a vessel of a certain flag and the smugglers start to use a different flag?" The outputs of the model would reflect the performance under these conditions. Modifications to the traffic description and decision matrices allow the model to be used for this type of analysis.

3.4 SMUGGLER TACTICS

The model can also be used to study ELT in a more global manner by analyzing ELT effectiveness in a number of areas and postulating changes in traffic patterns as a function of tactical and policy decisions in one specific area.

3.5 ENVIRONMENT

Environmental factors have serious effects on all Coast Guard missions because of their effect on speed in the seaway, fuel usage in heavy seas, equipment and personnel performance, and the need to divert to SAR missions in heavy weather. Environmental factors can be incorporated into the model by modifications to inputs and also by additional diversions from the ELT mission.

3.6 SATURATION AND LOADING

The present model assumes that the cutter always continues to prosecute a contact until it either decides that it is no longer interested in the vessel or it seizes the vessels. Consequently, the only other task the cutter can perform while prosecuting is searching. Any detections that occur while the cutter is prosecuting a vessel must be dropped. The cutter can be said to be saturated if it cannot prosecute a contact. The number of detections that occur while the cutter is otherwise preoccupied is presented as an indication of the degree of saturation or loading. Examples of saturation are included in appendix B.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The approach taken in building this model is to develop a number of algorithms that do the calculations needed to solve the more tedious equations. An ELT mission, in reality, is composed of a number of separate phases and events. It is likely, for instance, that vessel traffic will change over a long period of time, but not significantly during a mission. Environmental conditions also change during a patrol. The analyst can construct an ELT mission composed of transits, refuelings, diversions for SAR, other diversions, and a number of ELT cycles that are performed under various environmental and tactical conditions. The analyst can then tally the performance of the cutter over the whole mission and compute any of a number of measures of effectiveness. Used in this manner, the model can be applied to realistic scenarios.

The model is sensitive to craft characteristics, environmental factors, tactical decisions, and policy decisions. Consequently, the model has applications in a number of areas such as platform development, tactical analysis, and policy evaluation in various environments and scenarios.

The model produces classes of output (performance measures, allocation of effort, and logistic information) that can be used to analyze an ELT mission. The output is helpful in sensitivity analysis since the histograms help identify factors that can be changed to improve the MOEs.

4.2 RECOMMENDATIONS

A number of recommendations are made that will facilitate the use of the ELT model for analytical work. These are:

1. Install the model as described in this report on the VAX II - 750 in Coast Guard Headquarters (G-D) using structured programming techniques

2. Develop the necessary procedures and programs to use the ELT and AMV data bases as inputs and/or outputs for the model.

3. Modify and expand the model so it can be used to analyze fisheries patrols. Refine the model to account for additional ways of performing a law enforcement patrol.

4. Investigate the statistical aspects of the model, i.e. determine distributions, variances and confidence intervals.

APPENDIX A
COMPUTATIONS

A.1 INTRODUCTION

The computerized ELT model solves the network in figure A-1. The solution of the network involves calculating the number of times the cutter must execute each phase (search, close, come alongside, board, and escort) of the mission to effect one seizure. The program computes the probability that the cutter will revert to search after each phase of the cycle (P_{io}) and the number of times each phase must be executed to effect one seizure (N_i). Using the average time to perform a phase once (μ_i), it is possible to compute the average total time spent in each phase ($\bar{T}_i$) in order to effect one seizure and also the average total mission time required to effect one seizure (T_{CYCLE}). Once this network is solved, computing MOEs is fairly straightforward.

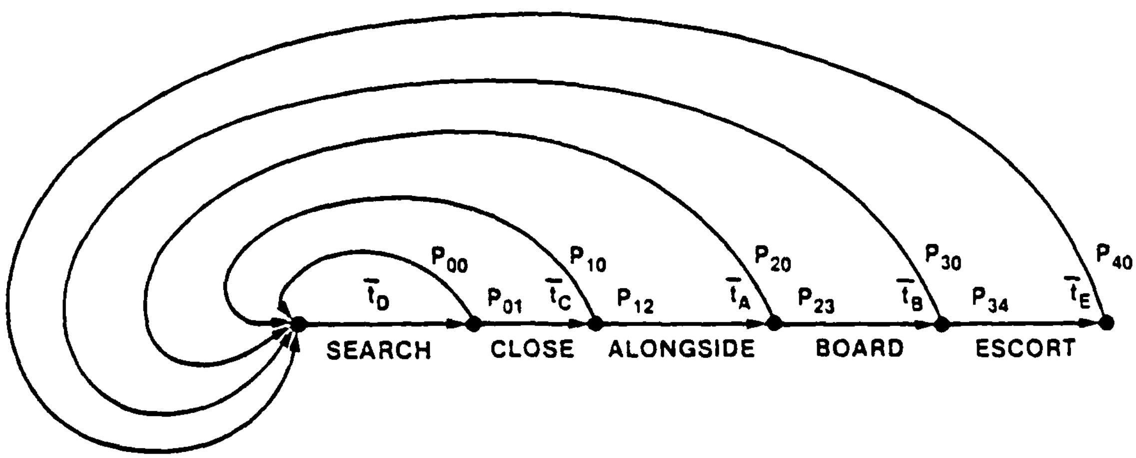

Figure A-1. ELT Network

A.2 COMPUTATION OF AVERAGE TIME PER TASK

The average time to perform an individual task is a key building block of the ELT model. These times are also important in sensitivity analysis since they suggest areas where significant improvements can be made in ELT performance. These factors are computed as follows.

A.2.1 Average Time to Detect

Detection is a function of target, environment, sensors, tactics, and time. Since radar detection is assumed, target size and height, weather and cutter stability, mast height and radar all affect the probability of detection. All of these factors as well as the effect of seakeeping on operator performance are incorporated into the average sweep width. The size of the area to be searched, cutter speed, and the average traffic speed through the area also affect detection.

In the ELT model, the issue is not specifically the probability of detection, but rather the average time to detect any one vessel in the operating area. The approach used to compute the average time to detect entails a three-step process:

1. Determine the average sweep width,

2. Compute the probability of detecting one vessel in time t, and

3. Compute the average time to detect one vessel.

Many search tactics can be employed on an ELT patrol. Three search tactics and appropriate equations for each tactic are included in this report.

Random search is used if the cutter has the least possible information about the traffic. It is assumed only that the target is randomly distributed in the search area and that the cutter searches randomly (see figure A-2). A lower bound for the probability of detection is:

$$P_D = 1-e^{-WL/A} ,$$

where W is sweep width and P_D is the probability that detection will occur by the time the observer has traveled L nautical miles through area A. Since L is V_S*t, the equation can be rewritten as:

$$P_D = 1-e^{-\left(\frac{WV_S}{A}\right)t} .$$

Let $\lambda = W*V_S/A$ and the average time to detect a vessel is $\bar{t}_D$, which equals $1/\lambda$. If more than one vessel is in the search area, the area is divided by the number of vessels to give A, which is defined as the average area containing one vessel. (All probability of detection equations are taken from reference 6.)

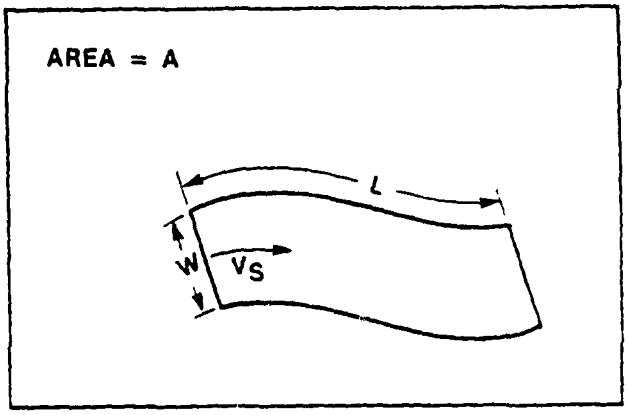

Figure A-2. Random Search

On an ELT mission, the cutter is often patrolling a barrier in a choke point. If the cutter has a significant speed advantage over the traffic, it can use a crossover barrier. Otherwise, it must use a linear barrier. The geographic tracks and relative tracks of the cutter for both tactics are shown in figure A-3. It is convenient to introduce two new variables, $r = u/v$ where v is cutter speed and u is vessel speed and $\lambda = D'/W$. For the crossover barrier, the probability of detection is given by:

$$P_{\infty} = 1, \text{ or } \left(1 + \frac{r\sqrt{r^2-1}}{r+1}\right)\frac{1}{\lambda + 1} ,$$

whichever is smaller. Since the time t to complete one half cycle is $(H + M)/v$, P_{∞} can be considered as the probability of detection after the cutter has been searching time t.

For the linear patrol, the probability of detection is given by:

$$P_{\leftrightarrow} = \begin{cases} 1 - \left[\left(\lambda - \dfrac{\sqrt{r^2+1} - 1}{2}\right)^2 / \lambda(\lambda + 1)\right], & r \leq 2\sqrt{\lambda(\lambda + 1)} \\ 1 & , \quad r > 2\sqrt{\lambda(\lambda + 1)} \end{cases}$$

the time t to complete one half cycle is D_1/v.

Track spacing, S, is computed using the equations in figure A-3. Knowing the infiltration rate (R), S, and the time to complete one half cycle, it is possible to compute the expected number of vessels in the area during time t (for random search, S is the depth of the search area and t is the average traffic transit speed).

$$E_A = R * S/t .$$

The expected number of detections in time t is:

$$E_D = E_A * P_D .$$

and the average time to detect is therefore:

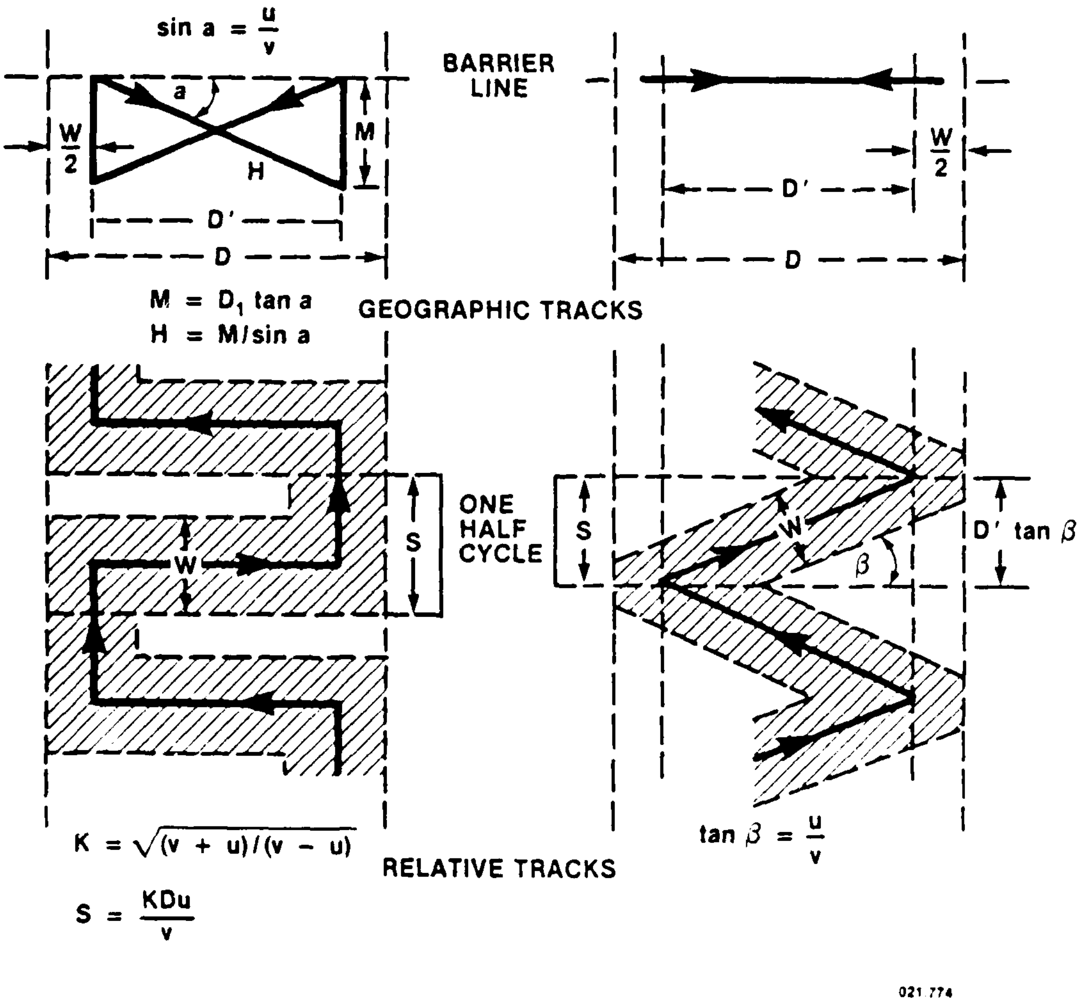

Figure A-3. Barrier Patrol

$$\bar{t}_D = \frac{t}{\bar{t}_D} .$$

A.2.2 <u>Average Time to Intercept</u>

The intercept algorithm assumes that detections occur at maximum detection range. In a barrier patrol, the cutter is possibly transiting across the barrier and intercepting vessels that are approaching the U.S. (see figure A-4).

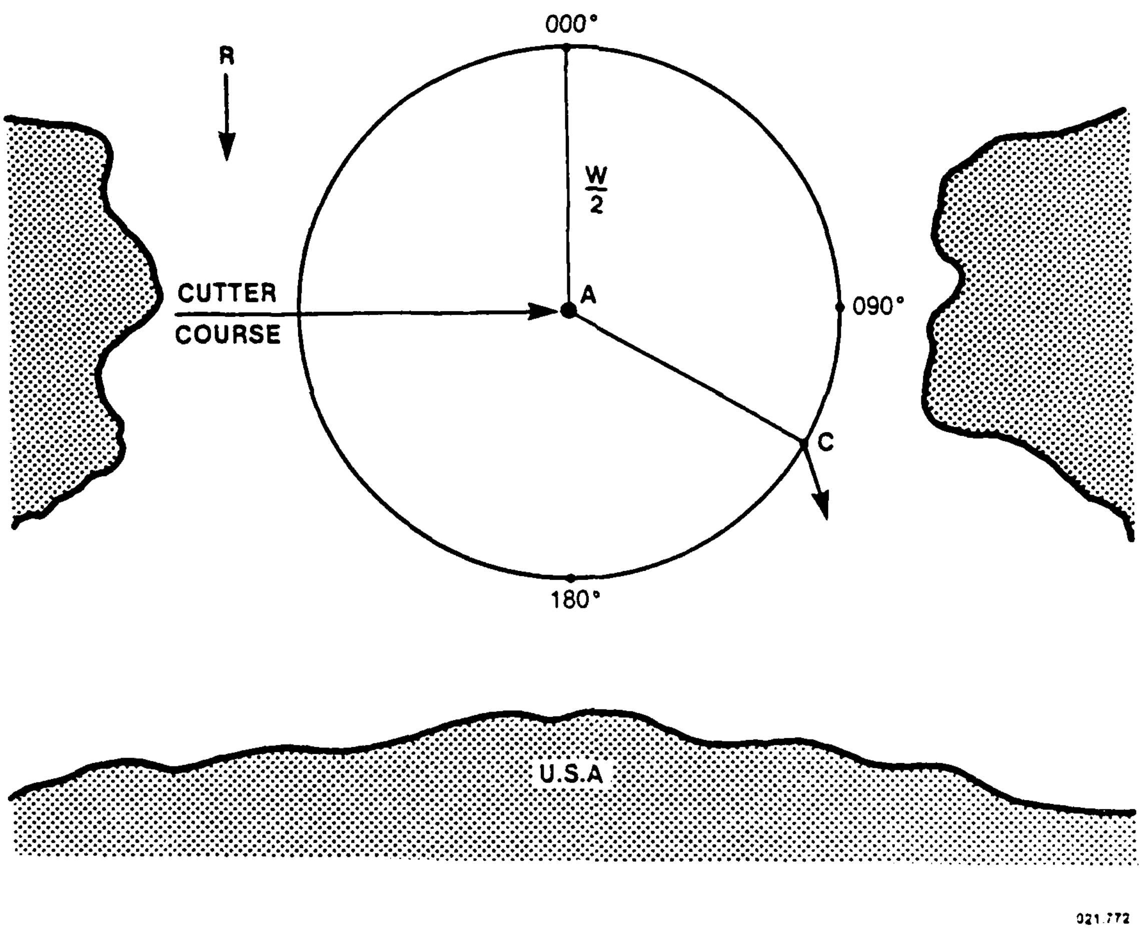

Figure A-4. Intercept Geometry

Since the cutter is generally searching at a speed that is greater than the average traffic speed, most detections will occur in the forward hemisphere. A contact at 000 would be closing the cutter, while a contact at 180 would be opening the cutter. The detected vessel is assumed not to change its course or speed while the cutter is intercepting. Consequently, it is possible to assume that a vessel detected at maximum range could be traveling in any direction (but not all equally likely) relative to the cutter. Assume that a cutter located at A detects a vessel at C and sets a course to close. Since C is a random point on the radar envelope curve, the vessel could be on any possible course relative to the cutter. Figure A-5 depicts a representative geometry.

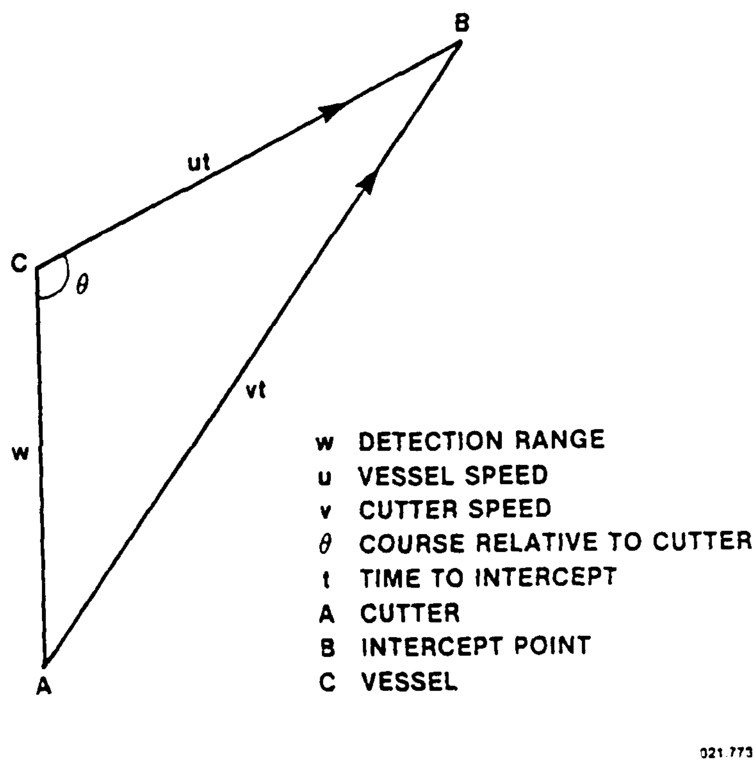

Figure A-5. Representative Intercept Geometry

Using the law of Cosines,

$$u^2t^2 + w^2 - 2utw \cos\theta = v^2t^2 ,$$

and rearranging:

$$(u^2-v^2)t^2 - 2uw \cos\theta(t) + w^2 = 0 .$$

Using the quadratic formula to solve for t:

$$t = \frac{2uw \cos\theta - [4u^2w^2 \cos^2\theta - 4(u^2-v^2)w^2]^{.5}}{2(u^2-v^2)}$$

$$= \frac{2uw \cos\theta - [4u^2w^2 \cos^2\theta - 4(u^2 - \frac{u^2v^2}{u^2})w^2]^{.5}}{2(u^2-v^2)}$$

$$= \frac{uw [\cos\theta - (\cos^2\theta - 1 + \frac{v^2}{u^2})^{.5}]}{(u^2-v^2)}$$

The equation is continuous from θ equals 0 to θ equals 180 degrees.

Using a computer program to iterate from $\theta = 0$ to $\theta = 180$ (figure A-6), it is possible to compute an average time to intercept. The discrete probability density function called "WEIGHT" in the algorithm is a uniform distribution. If the scenario requires a nonuniform distribution of contact bearings, this function can be changed to an appropriate nonuniform distribution. Appendix C contains some examples of the average time to intercept for a range of values of w, u, and v.

Intercept is divided into two subphases:

Close -- from radar detection range to visual classification.

Bring alongside -- from visual classification to arrival on scene.

```
140   SUB Close(U,V,W)
150   DEG
160   DIM Weight(18)
170   DATA .0526,.0526,.0526,.0526,.0526,.0526,.0526,.0526,.0526,.0525
180   DATA .0526,.0526,.0526,.0526,.0526,.0526,.0526,.0526,.0526
190   MAT READ Weight
200   FOR Theta=0 TO 180 STEP 10
210   I=Theta/10
220   Root=(V^2/U^2-1+COS(Theta)^2)^.5
230   T=W+U*(COS(Theta)-Root)/(U^2-V^2)
240   Tavg=Tavg+T*Weight(I)
250   PRINT USING "K,DDDD,K,DD.DD";"THETA= ";Theta,"        TIME(HOURS)=  ";T
260   NEXT Theta
270   PRINT USING "//K,DD.DD,K";"AVERAGE TIME: ",Tavg,"  (HOURS)"
280   SUBEND
```

Figure A-6. Program to Compute Average Time to Intercept

It is assumed that visual classification can occur at some fixed distance d_{CL}. Consequently, the average time to close to visual range is:

$$\bar{t}_V = \frac{W/2 - d_{CL}}{W/2} * \bar{t}_I$$

and the average time to continue closing to come alongside is:

$$\bar{t}_A = \bar{t}_I - \bar{t}_V .$$

These calculations assume that the vessel does not change speed when the cutter is in visual range of the vessel. The average time to check EPIC ($\bar{t}_{EPIC}$) should be added to $\bar{t}_V$ if it is a significant amount of time. Note that EPIC may not necessarily be checked for all vessels that are intercepted, and this factor should be included in the average time to check EPIC.

A.2.3 Average Time to Board

Boarding a U.S. registered vessel is a fairly straightforward process. Consequently, the average time to board a vessel of U.S. registry is:

$$\bar{t}_{B_{U.S.}} = \bar{t}_{BV} + \bar{t}_{SR} ,$$

which is the sum of the average time to board and the average time to search the vessel.

Boarding a foreign vessel, on the other hand, requires obtaining permission from the country of registry. The average time to board a foreign vessel is:

$$\bar{t}_{B_{FOR}} = \bar{t}_{SONO1} + \bar{t}_{BV} + \bar{t}_{SR} ,$$

where $\bar{t}_{SONO1}$ is the average time to obtain the statement of no objection to board the vessel. Consequently, the overall average time to board is:

$$\bar{t}_B = P_{B_{U.S.}} * \bar{t}_{B_{U.S.}} + P_{B_{FOR}} * \bar{t}_{B_{FOR}} ,$$

where $P_{B_{U.S.}}$ is the percent of boarded vessels that are U.S. flag and $P_{B_{FOR}}$ the percent of foreign flag vessels.

A.2.4 Average Time to Escort a Smuggler

Escorting a smuggler to a hand-off point involves four tasks:

1. Effecting a seizure,
2. Escorting the smuggler at smuggler's transit speed,
3. Processing legal papers and handing the seized vessel to authorities, and
4. Returning to the operating area at cutter's transit speed.

As with boarding, seizing of foreign vessels requires obtaining a SONO to seize. Therefore, the average time to escort is given by:

$$\bar{t}_E = \bar{t}_{SZ} + P_{E_{FOR}} * \bar{t}_{SONO2} + \frac{D_E}{U_T} + \bar{t}_{LG} + \frac{D_E}{V_T} .$$

where:

$\bar{t}_{SZ}$ is average time to seize,

D_E is the distance to the hand-off point,

U_T is vessel transit speed,

V_T is cutter transit speed, and

$\bar{t}_{LG}$ is the average time to complete legal work.

Although the ELT model assumes independence of the six phases of the ELT mission, two exceptions are made in this phase. First, if the cutter is escorting the smuggler to a port, it is likely that the cutter can refuel either while legal paperwork is being completed or at least before returning to station. Also, if the total mission time has nearly expired, the cutter would probably not return to station only to turn around and come home. These factors can be easily handled as the analyst is computing the number of cycles that can be completed during an ELT mission.

A.2.5 Average Time Diverted from ELT Mission

A considerable amount of total mission time is consumed by tasks other than searching for smugglers. This time includes transit time and time diverted to other tasks. The average time to transit to or from the operating area is:

$$t_T = \frac{D_T}{V_T} ,$$

where D_T is the distance from home port to the operating area and V_T is transit speed. The cutter may not have to transit back to port if a mission ends with the cutter escorting a smuggler to port.

The cutter is diverted from the ELT mission for a number of reasons including SAR, weather, fatigue, and the need to refuel. Refueling requirements are a function of speed, sea state, time, and topping-off policy. Using fuel consumption curves, the analyst computes fuel usage during the different phases of the mission. Taking advantage of convenient opportunities to refuel during port calls, the analyst must compute the number of additional refuelings necessary. The equation for the average time to refuel is:

$$t_R = \frac{D_R}{V_T} + t_{RF} + \frac{D_R}{V_T} ,$$

where D_R is the distance to the refueling point and t_{RF} is the average time required to replenish the cutter.

The other diversions can be incorporated into the model by decreasing the on-station time by a certain percent or amount that covers all other categories of diversions.

A.3 TRANSITION PROBABILITIES

This section discusses the computation of the transition probabilities in the ELT network (see figure A-1).

The probability that a cutter will close a vessel it detects (P_{01}) is computed by multiplying the probability that a vessel is of a particular class and the probability that a class is closed and then summing over all classes.

The probability that the cutter will come alongside a vessel it closes (P_{12}) is computed by multiplying the probability that a category of vessel is closed and the probability that that category is brought alongside and then summing over all classes and flags.

The probability that a vessel will be boarded (P_{23}) is a function of the special-interest decision as well as the boarding policy. This probability is computed by the following equation:

$$P_{23} = \Sigma_{Types}\left[P_{Alongside} * P_{SI} * P_{Board|SI} + P_{Alongside} * P_{\overline{SI}} * P_{Board|\overline{SI}}\right]$$

where

P_{SI} is the probability that a vessel is of special interest,

$P_{\overline{SI}}$ is the probability that a vessel is not of special interest, and

$P_{Alongside}$ is the probability that a vessel is alongside.

The probability that a vessel is escorted (P_{34}) is the probability that it is a smuggler, given that it is boarded. It is computed by multiplying as follows:

$$P_{34} = \Sigma_{Types} \left[P_{Alongside} * P_{SI} * P_{Board|SI} * P_{Smug|SI} + P_{Alongside} * P_{\overline{SI}} * P_{Board|\overline{SI}} * P_{Smug|\overline{SI}} \right]$$

The remaining probabilities on the network are easily computed:

$$P_{00} = 1 - P_{01}$$

$$P_{10} = 1 - P_{12}$$

$$P_{20} = 1 - P_{23}$$

$$P_{30} = 1 - P_{34}$$

$$P_{40} = 1$$

These probabilities may be expressed in what is commonly known as a transition matrix, i.e.,

$$P_{ij} = \begin{bmatrix} P_{00} & P_{01} & 0 & 0 & 0 \\ P_{10} & 0 & P_{12} & 0 & 0 \\ P_{20} & 0 & 0 & P_{23} & 0 \\ P_{30} & 0 & 0 & 0 & P_{34} \\ P_{40} & 0 & 0 & 0 & 0 \end{bmatrix}$$

where P_{ij} is the probability that a cutter performing task i will next perform task j.

The sum of the probabilities emanating from each node is 1.0. Therefore, the sum of each row in the transition matrix is 1.0.

A.4 NETWORK SOLUTION

The next task is to solve the network to determine the average time required to effect one seizure (T_{CYCLE}). Once this time is determined, it is possible to compute fuel usage during a complete cycle. This information enables the user to determine the number of diversions needed for refueling and the number of cycles that can be completed during a mission.

The network is a semi-Markov process since the time steps are not uniform. To conform to common notation, the average times for each task are expressed by the variable μ_i as shown below.

$$\mu_0 = \bar{t}_D$$

$$\mu_1 = \bar{t}_V$$

$$\mu_2 = \bar{t}_A$$

$$\mu_3 = \bar{t}_B$$

$$\mu_4 = \bar{t}_E$$

We can solve for the steady-state probabilities in the semi-Markov model by first solving the equations below for the embedded chain steady-state probabilities π_j .

$$\pi_j = \sum_{i=0}^{4} \pi_i P_{ij} \quad \text{and} \quad \sum_{i=0}^{4} \pi_i = 1.0 \quad j=0,1,\ldots,4$$

Since most of the probabilities in the matrix are zero, the system can be expressed as a set of simultaneous equations which are easily solved.

$$\pi_0 = P_{00} * \pi_0 + P_{10} * \pi_1 + P_{20} * \pi_2 + P_{30} * \pi_3 + P_{40} * \pi_4$$

$$\pi_1 = P_{01} * \pi_0$$

$$\pi_2 = P_{12} * \pi_1$$

$$\pi_3 = P_{23} * \pi_2$$

$$\pi_4 = P_{34} * \pi_3$$

$$1 = \pi_0 + \pi_1 + \pi_2 + \pi_3 + \pi_4$$

One equation is redundant. If the first equation is eliminated, the system can be readily solved by substitution into the last equation yielding an equation in one unknown:

$$\pi_0 = 1/\left[1 + P_{01} + (P_{01} * P_{12}) + (P_{01} * P_{12} * P_{23}) + (P_{01} * P_{12} * P_{23} * P_{34})\right]$$

or

$$\pi_0 = 1/(1 + P_{01}\ (1 + P_{12}(1 + P_{23}(1 + P_{34}))))$$

The other steady-state probabilities are then solved sequentially by substitution.

One complete cycle includes a number of detections, closings, and boardings, but only one seizure. The number of times that each phase of the cycle is performed to effect one seizure is:

$$N_i = \frac{\pi_i}{\pi_4} \quad i = 0,1,\ldots,4$$

and the average time spent in each phase of one complete cycle is:

$$T_i = N_i * \mu_i \quad .$$

The average time to complete one search through escort cycle is:

$$T_{CYCLE} = \sum_{i=0}^{4} N_i * \mu_i$$

or

$$T_{CYCLE} = T_S + T_V + T_A + T_B + T_E$$

Although in this model a complete ELT cycle ends in the fifth phase with the cutter escorting the seized vessel, cycles ending at closing (phase 3) or boarding (phase 4) are also of interest. A cycle can actually be limited to search (only 1 phase). The time, T_j, to complete a cycle through the jth phase of the operation is:

$$T_j = \frac{\sum_{i=0}^{j} \pi_i \;\; \mu_i}{\pi_j}$$

and the amount of time, t_{ij}, spent in the ith phase of the jth cycle is:

$$t_{ij} = \frac{\pi_i \; \mu_i}{\pi_j} \quad .$$

The average number of times, N_{ij}, that the ith task is performed in the jth cycle is:

$$N_{ij} = \frac{\pi_i}{\pi j}$$

The total time in any cycle is the sum of the average time to perform the task multiplied by the number of times the task is performed in the cycle. The sample problem in appendix 3 includes computations for these values.

A.5 MEASURES OF EFFECTIVENESS

Once the average time to complete one cycle has been determined, it is possible to compute the interdiction rate. The model computes the average tonnage of marijuana found on a smuggler that is seized ($TONS_{seized}$). This is computed by summing over all types of vessels the product of the probability that a vessel is seized and the average tons of marijuana on a vessel of that type. This is, in effect, the average tons of contraband seized during T_{CYCLE}. Since the programs also compute the average tons infiltrating per hour ($TONS_{shipped}$), the on-scene infiltration rate is:

$$I_{On-Scene} = \frac{TONS_{seized}}{T_{CYCLE} * TONS_{Shipped}}$$

The number of cycles that can be completed during a mission can easily be determined. Subtracting transit, diversion (SAR, weather, night), and refueling times from total mission time enables the analyst to determine the number of cycles (N_c) that can be completed. The overall interdiction rate, therefore, is:

$$I_{OVERALL} = \frac{N_c * TONS_{Seized}}{T_M * TONS_{Shipped}} .$$

where T_M is total mission time.

In evaluating the relative performance of advanced marine vehicles, it is informative to compute an interdiction rate for the cutter. Since some vessels require extensive down-time between missions, the MOE is defined as:

$$I_{CUTTER} = \frac{N_c * TONS_{Seized}}{(T_{DOWN} + T_M) * TONS_{Shipped}}$$

where T_{DOWN} is the amount of time the cutter must spend in port between ELT missions.

In a similar manner, it is possible to compute a number of other MOEs such as seizure rate, number seized, number missed, tonnage seized, tonnage missed, etc.

It is not realistic to assume that cutter performance would remain constant over a long mission since traffic density, weather, and the need to divert to other tasks change with time and season. The ELT model can compute measures of effectiveness such as infiltration rate for a range of operating conditions. Determining the percent of time the cutter is operating under the various conditions, it is possible to compute an overall MOE. If a cutter seizes 10 percent of contraband during good weather but only 5 percent during bad weather and bad weather comprises 25 percent of the mission time, then the overall MOE is:

$$I = \frac{3}{4}(10) + \frac{1}{4}(5) = 8.75 \text{ percent .}$$

APPENDIX B
SAMPLE RUN AND SENSITIVITY ANALYSIS

B.1 CALCULATIONS

An example of ELT calculations using a hypothetical scenario and hypothetical data is presented in this section. Section B.2 contains examples of sensitivity analysis. A high-endurance cutter is deployed on a 60-day mission. During the patrol, the cutter is diverted from ELT for a total of 6 days for SAR missions. The cutter takes four days for replenishment, but performs the ELT mission around the clock on all remaining days. Figure B-1 contains the inputs for the analysis. Sheet 1 is the description of the traffic, sheet 2 is the Coast Guard decision matrix, and sheet 3 contains the remaining inputs.

The average times to perform each phase once are computed using the equations in appendix A (see figure B-2). These values are entered into the ELT model on the HP 9845 computer, which computes the transition probabilities, the steady-state probabilities, the number of times each phase is performed to effect a seizure, the total time devoted to each phase of the operation, and the on-scene interdiction rate (see figure B-3). With this information, it is possible to compute fuel consumption, which is straightforward arithmetic (see figure B-4).

The 60-day mission is divided as follows:

- 1 day transit to station
- 6 days diverted to SAR
- 4 days replenishment/port visit
- 48 days regular operations
- 1 day return

8 MARCH 1983

INPUT SUMMARY

**DESCRIPTION OF SHIPPING

NUMBER OF CRAFT OF EACH TYPE ENTERING THE OP AREA PER DAY

TYPE				
BIG	MERCHANT	FISHING	FAST	
11.00	8.00	4.00	4.00	U.S. VESSELS
3.00	7.00	2.00	6.00	HIGH INTEREST FOREIGN VESSEL
3.00	2.00	2.00	1.00	ALL OTHER FOREIGN VESSELS

THREAT TRANSIT SPEED (KNOTS)

15.00	10.00	8.00	15.00	ALL VESSELS

THREAT EVASION SPEED (KNOTS)

20.00	20.00	15.00	30.00	ALL VESSELS

PERCENT OF SPECIAL INTEREST THAT ARE SMUGGLERS

.10	.70	.80	.40	U.S. VESSELS
.20	.90	.70	.40	HIGH INTEREST FOREIGN VESSEL
.10	.50	.60	.40	ALL OTHER FOREIGN VESSELS

PERCENT NOT OF SPECIAL INTEREST THAT ARE SMUGGLERS

0.00	.10	.10	.10	U.S. VESSELS
0.00	.20	.20	.20	HIGH INTEREST FOREIGN VESSEL
0.00	.10	.10	.10	ALL OTHER FOREIGN VESSELS

AVERAGE NUMBER OF TONS OF CONTRABANT ON SMUGGLER OF THIS TYPE

0.00	3.00	7.00	1.00	U.S. VESSELS
1.00	2.00	10.00	1.00	HIGH INTEREST FOREIGN VESSEL
0.00	3.00	7.00	2.00	ALL OTHER FOREIGN VESSELS

Figure B-1. Inputs -- Traffic Description (sheet 1 of 3)

**DECISION PROCESS

	TYPE			
BIG	MERCHANT	FISHING	FAST	
1. DECISION TO CLOSE				
PERCENT DETECTED TO BE CLOSED				
0.00	.90	.90	0.00	ALL VESSELS
2. DECISION TO COME ALONG SIDE				
PERCENT CLOSED TO BE BROUGHT ALONG SIDE				
0.00	.70	.70	0.00	U.S. VESSELS
0.00	.80	.70	0.00	HIGH INTEREST FOREIGN VESSEL
0.00	.80	.20	0.00	ALL OTHER FOREIGN VESSELS
3. DECISION ON BOARDING				
PERCENT THAT ARE OF SPECIAL INTEREST				
0.00	.80	.80	0.00	U.S. VESSELS
0.00	.90	.70	0.00	HIGH INTEREST FOREIGN VESSEL
0.00	.80	.20	0.00	ALL OTHER FOREIGN VESSELS
PERCENT SPECIAL INTEREST TO BE BOARDED				
0.00	.60	.65	0.00	U.S. VESSELS
0.00	.50	.55	0.00	HIGH INTEREST FOREIGN VESSEL
0.00	.40	.45	0.00	ALL OTHER FOREIGN VESSELS
PERCENT NOT OF SPECIAL INTEREST TO BE BOARDED				
0.00	.30	.35	0.00	U.S. VESSELS
0.00	.20	.25	0.00	HIGH INTEREST FOREIGN VESSEL
0.00	.10	.15	0.00	ALL OTHER FOREIGN VESSELS

Figure 3-1. Inputs -- Decision Matrices (sheet 2 of 3)

FUEL CONSUMPTION DATA

PHASE	KNOTS	GAL/HOUR
Standby	0	100
Transit	11	300
Search	18	600
Intercept	29	1600

SYMBOL	VALUE	DESCRIPTION
W	30	Sweep width
$\bar{t}_{BV}$	1	Average time to board
$\bar{t}_{SR}$	2	Average time to search
$\bar{t}_{LG}$	4	Average time to complete legal work
$\bar{t}_{RF}$	8	Average time to refuel
$\bar{t}_{SZ}$	2	Average time to seize
$\bar{t}_{SONO1}$	24	Average time to obtain SONO to search
$\bar{t}_{SONO2}$	12	Average time to obatin SONO to seize
D_{CL}	3	Visual detection range
D	75	Width of search area
S	70	Depth of search area
D_T	225	Distance to transit to search area
D_E	225	Distance to escort smuggler
D_R	100	Distance to refuel
F_C	250,000 gal	Fuel capacity
F_R	@ 60% consumption	Refueling policy

Notes: All times in hours and all distances in nautical miles.
Fuel data for a 4000-ton warship.

Figure 3-1. Inputs -- Fuel Consumption Data and Other Inputs (sheet 3 of 3)

$$\bar{t}_T = \frac{D_T}{V_T} = \frac{225}{11} = 20.5$$

$$\bar{t}_R = \frac{D_R}{V_T} + \bar{t}_{RF} + \frac{D_R}{V_T} = \frac{100}{11} + 8 + \frac{100}{11} = 26.2$$

$$E_A = \frac{RS}{t} = \frac{(53/24)(40)}{12.24} = 7.16$$

$$A = \frac{DS}{7.16} = \frac{75(40)}{7.16} = 419$$

$$\lambda = \frac{WV_S}{A} = \frac{30(18)}{419} = 1.28$$

$$\bar{t}_I = \mu = \frac{1}{\lambda} = .78$$

$$\bar{t}_I \approx .76 \text{ (computer algorithm)}$$

$$\bar{t}_V = \frac{W/2 - d_{CL}}{W/2} (\bar{t}_I) = \frac{15 - 3}{15} (.76) = .61$$

$$\bar{t}_A = \bar{t}_I = \bar{t}_V = .76 - .61 = .15$$

$$\bar{t}_B = \bar{t}_{BV} + \bar{t}_{SR} + P_{B_{FOR}} \bar{t}_{SONO1} = 1 + 2 + .46(24) = 14.0$$

$$\bar{t}_E = \bar{t}_{SZ} + P_{E_{FOR}} \bar{t}_{SONO\ 2} + \frac{D_E}{U_T} + \bar{t}_{LG} + \frac{D_E}{V_T} = 2 + .50(12) + \frac{225}{9.5} + 4 + \frac{225}{11} = 56.1$$

Figure B-2. Average Time Calculations

```
TOTAL NUMBER OF SHIPS ENTERING AREA PER DAY:  53

AVERAGE SPEED OF TRANSITING VESSELS  (KNOTS) 12.34

AVERAGE SPEED OF ESCORTED VESSELS     (KNOTS)  9.46

AVERAGE SPEED OF VESSEL TO BE CHASED (KNOTS  13.40

TONAGE OF CONTRABAND ENTERING AREA PER DAY   53.58


PERCENT CLOSED   .42
PERCENT BROUGHT ALONGSIDE  .30
PERCENT BOARDED   .15
    PERCENT BOARDED THAT ARE US  .54
    PERCENT BOARDED THAT ARE FOREIGN  .46
PERCENT ESCORTED   .11
    PERCENT ESCORTED THAT ARE US  .50
    PERCENT ESCORTED THAT ARE FOREIGN  .50
AVERAGE TONS OF CONTRABAND PER SEIZURE 4.04
AVERAGE TONS OF CONTRABAND PER HOUR    2.65

TRANSITION                  AVERAGE TIME TO
PROBABILITIES               PERFORM A TASK ONCE


P01(CLOSE)  - .42           DETECT  -   .78
P12(ALONG)  - .70           CLOSE   -   .61
P23(BOARD)  - .49           ALONG   -   .15
P34(SEIZE)  - .73           BOARD   - 14.00
                            SEIZE   - 56.10

NETWORK SOLUTION


EMBEDDED CHAIN            NUMBER OF TIMES           AVERAGE TOTAL TIME
PROBABILITIES             PHASE IS PEFORMED         IN PHASE
Pi(0)    .51              N(0)   9.46               T(0)   7.08
Pi(1)    .22              N(1)   4.01               T(1)   2.45
Pi(2)    .15              N(2)   2.79               T(2)    .42
Pi(3)    .07              N(3)   1.38               T(3)  19.29
Pi(4)    .05              N(4)   1.00               T(4)  56.10


TOTAL CYCLE TIME (HOURS) :   86
TOTAL TONS SHIPPED       :  227

ON-SCENE INTERDICTION RATE:  .013
```

Figure 3-3. ELT Model Output

PHASE	FUEL CONSUMPTION			
	TIME	GAL/HOUR	GALLONS (000)	PERCENT CAPACITY
Transit	20.5	300	6.1	2.5
Refuel	26.2*	300	5.5	2.2
Cycle				
Search	7.38	600	4.4	1.7
Close	2.45	1600	3.9	1.6
Alongside	.42	1600	.7	.2
Board	19.32	100	1.9	.7
Escort	56.1	300	16.8	6.7

*8 hours at port.

Figure B-4. Fuel Consumption

A complete cycle leading to one seizure requires 86 hours or approximately 3.6 days and uses 11 percent of fuel capacity. Since 48 days are available for ELT operations, the cutter can complete 13 seizures during a mission. The cutter presumably can refuel at the hand-off point and therefore does not have to divert to refuel.

The interdiction rate while the cutter is on-scene is .018. The total number of seizures is 13.

Total tons seized is:

$$13\ (4.04) = 52.5 \text{ tons},$$

while total tons shipped during the patrol is:

$$60(24)(2.65) = 3816 \text{ tons}.$$

Consequently, the mission interdiction rate is:

$$\frac{48.5}{3816} = .014\ .$$

Matrices of the average time spent in each phase of the cycle and the average number of times each phase is completed in a cycle can be computed for all possible cycles using the equations in section A.4 (see figure B-5).

The matrices in figure B-5 show how the time is allocated in a cycle. For example, the fourth row is the cycle from search through boarding. 21.43 hours are required to effect one boarding. This includes 5.35 hours searching, 1.78 hours closing to visual, .30 hours closing alongside, and 14 hours boarding. The 5.35 hours searching resulted in 6.86 detections. The fifth row contains the data for a complete search through escort cycle, and it is identical to the computer output (see figure B-3). The diagonal of the average time matrix is the average time to perform each task once. (The diagonal of the number of times tasks are performed contains all ones).

The times spent in each phase of a cycle and the total time of a cycle are:

CYCLE Search to:	PHASE Search	Close V	Close A	Board	Escort	Cycle Time
Detect	0.78	--	--	--	--	0.78
Close/Vis	1.84	0.61	--	--	--	2.45
Close/Along	2.64	0.88	0.15	--	--	3.67
Board/Inspect	5.35	1.78	0.30	14.0	--	21.43
Escort/Seize	7.38	2.45	0.42	19.29	56.1	85.64

Time in Phase (Hrs)

and the average number of times each task is performed in a cycle is:

CYCLE Search to:	PHASE Search	Close V	Close A	Board	Escort
Detect	1.00	--	--	--	--
Close/Vis	2.36	1.00	--	--	--
Close/Alongside	3.38	1.44	1.00	--	--
Board/Inspect	6.86	2.91	2.03	1.00	--
Escort/Seize	9.46	4.01	2.79	1.38	1.00

Figure B-5. Matrices

The output of the ELT model can be presented in a number of ways. The total time devoted to each phase of the ELT patrol (figure B-6) as well as the number of times each task is performed (figure B-7) can be plotted on a histogram.

The cutter will detect vessels during all phases of the ELT mission. Especially during transit, computing the average time to detect is both difficult and of dubious value. Since the traffic can change drastically as the cutter travels through port areas, channels, straits, etc., enroute to the operating area, the average time to detect also changes. If traffic density can be determined for the changing areas of the transit, then an average time to detect during transit could be computed.

Of more interest is the number of detections that would occur if the cutter were not diverted to transiting, boarding, escorting, refueling, performing SAR, or in port. These detections can be computed, using the average time to detect, and plotted (see figure B-8). This histogram gives an indication of overload since the cutter could not follow up these contacts.

B.2 SENSITIVITY ANALYSIS

The output of the sample run suggests areas for sensitivity analysis. Considerable time is spent boarding vessels and escorting smugglers. Sample runs were made looking at the effect of a reduction of these times on the MOE. If a prize crew could be used and hand-off time reduced to 8 hours, the interdiction rate is more than doubled. If average boarding time can be reduced to 4 hours, the MOE is increased by 25 percent. Another sensitivity run assumed that the cutter would search only during daylight hours. If the cutter stands by for 3 hours per day, the MOE is degraded by 33 percent. A more interesting alternative is to have the cutter not search during darkness, but otherwise continue to prosecute a contact. This can be modeled by adding a standby node to the network.

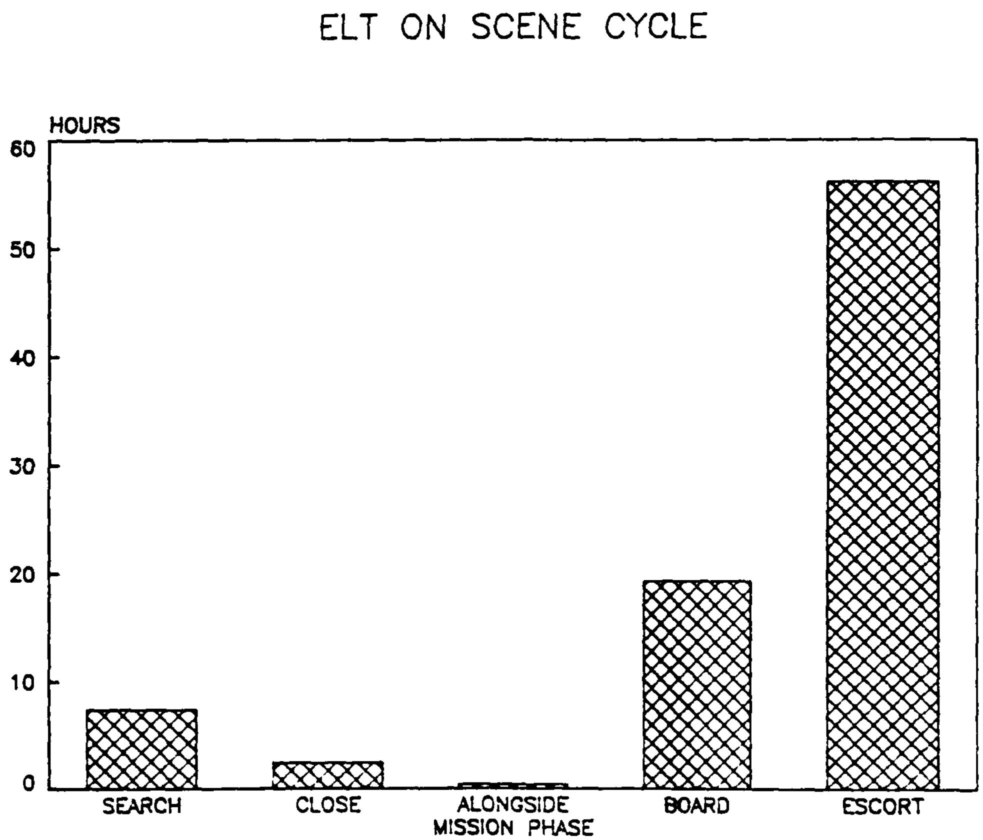

Figure B-6. Time Spent in Phase

ELT ON SCENE CYCLE

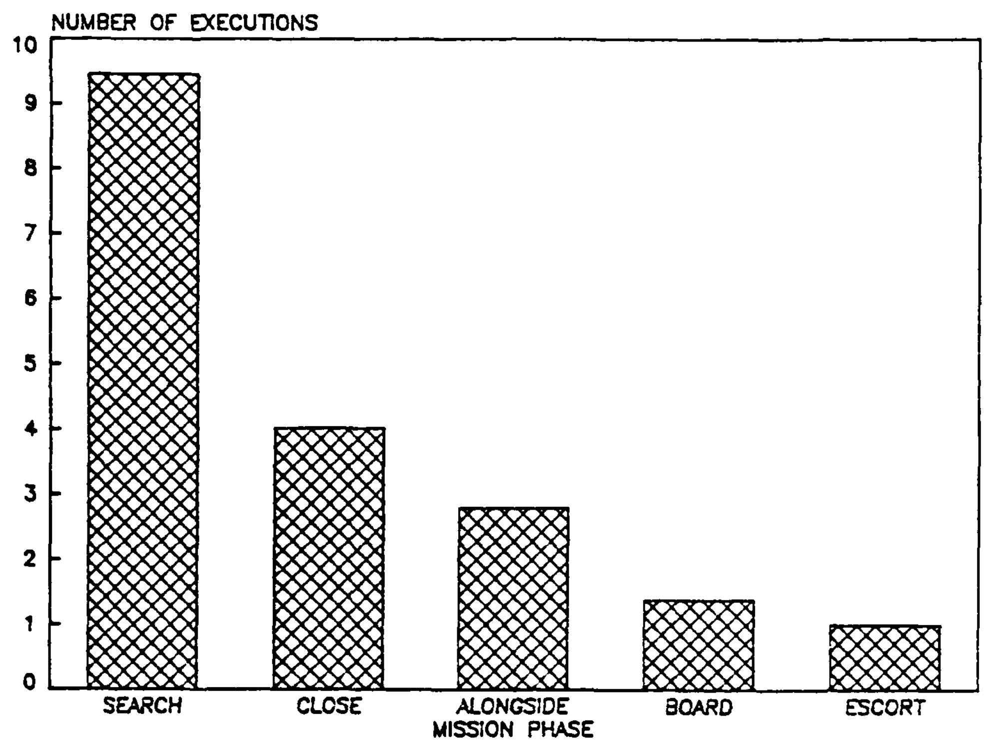

Figure B-7. Number of Times Phase is Performed to Effect One Seizure

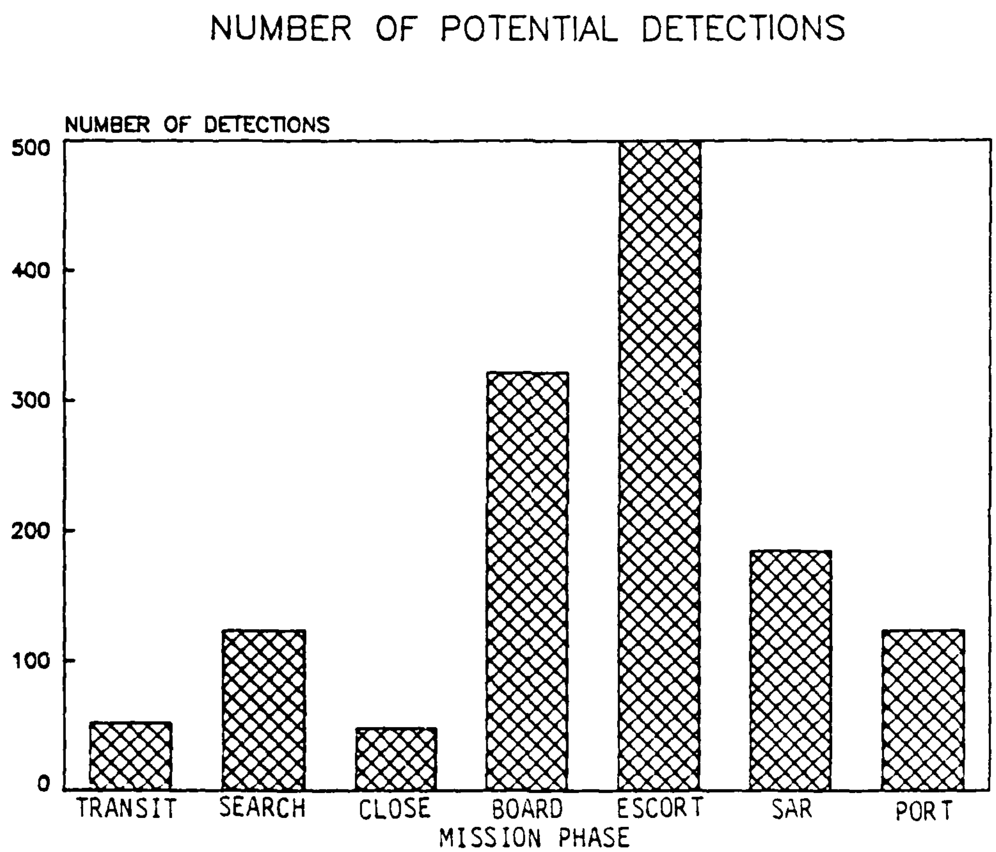

Figure B-8. Detections if Cutter Available to Search During Phases

As an example of sensitivity analysis, runs were made increasing intercept speed from 18 to 50 knots and plotting the percent improvement in interdiction rate (see figure B-9). The plot shows that the improvement in MOE is small and the increase in improvement beyond 34 knots is even smaller. Although the very high intercept speed provides little improvement in the interdiction rate, it does provide a capability to chase fast vessels. On the other hand, the model can be used to compute the effect on the MOE if a significant amount of drug traffic is carried on vessels that are faster than the cutter. This is done by changing the traffic description matrices and decision matrices.

These sensitivities are presented as some examples of sensitivity analysis using the ELT model. The model has the capability of computing the sensitivity of the MOE to changes in craft characteristics and tactics, especially changes that pertain to the use of advanced marine vehicles.

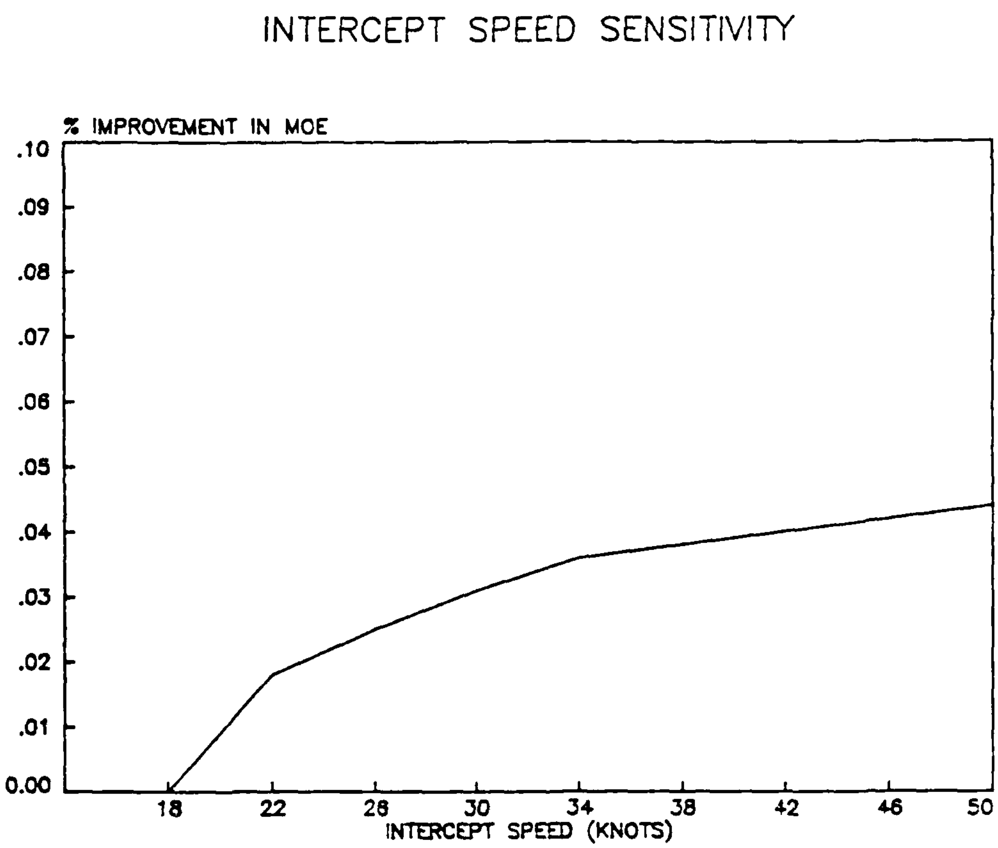

Figure B-9. Example of Sensitivity Analysis

APPENDIX C

EXAMPLE OF AVERAGE TIME TO INTERCEPT

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15 N.MI. (SWEEP WIDTH = 30 N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	(OVERALL) (HRS)
HEAD ON	0.	8.	16.	.625		
! C	10.	8.	16.	.630		
! L	20.	8.	16.	.644		
! O	30.	8.	16.	.669		
! S	40.	8.	16.	.705	.770	
! I	50.	8.	16.	.753		
! N	60.	8.	16.	.814		
! G	70.	8.	16.	.890		
!	80.	8.	16.	.979		
----------	90.	8.	16.	1.083	--------------	1.168
! O	100.	8.	16.	1.196		
! P	110.	8.	16.	1.317		
! E	120.	8.	16.	1.439		
! N	130.	8.	16.	1.556	1.566	
! I	140.	8.	16.	1.662		
! N	150.	8.	16.	1.752		
! G	160.	8.	16.	1.919		
!	170.	8.	16.	1.861		
CHASE	180.	8.	16.	1.875		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15.N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	8.	20.	.536		
! C	10.	8.	20.	.539		
! L	20.	8.	20.	.549		
! O	30.	8.	20.	.566		
! S	40.	8.	20.	.589	.629	
! I	50.	8.	20.	.620		
! N	60.	8.	20.	.659		
! G	70.	8.	20.	.705		
!	80.	8.	20.	.759		
----------	90.	8.	20.	.818	--------------	.856
! O	100.	8.	20.	.883		
! P	110.	8.	20.	.950		
! E	120.	8.	20.	1.016		
! N	130.	8.	20.	1.079	1.083	
! I	140.	8.	20.	1.136		
! N	150.	8.	20.	1.134		
! G	160.	8.	20.	1.220		
!	170.	8.	20.	1.242		
CHASE	180.	8.	20.	1.250		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15.N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	8.	30.	.395		
! C	10.	8.	30.	.396		
! L	20.	8.	30.	.401		
! O	30.	8.	30.	.409		
! S	40.	8.	30.	.420	.437	
! I	50.	8.	30.	435		
! N	60.	8.	30.	.452		
! G	70.	8.	30.	.472		
!	80.	8.	30.	.494		
----------	90.	8.	30.	.519	--------------	.529
! O	100.	8.	30.	.544		
! P	110.	8.	30.	.570		
! E	120.	8.	30.	.595		
! N	130.	8.	30.	.619	.620	
! I	140.	8.	30.	.640		
! N	150.	8.	30.	.658		
! G	160.	8.	30.	.671		
!	170.	8.	30.	.679		
CHASE	190.	8.	30.	.682		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15 N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	8.	40.	.313		
! C	10.	8.	40.	.313		
! L	20.	8.	40.	.316		
! O	30.	8.	40.	.321		
! S	40.	8.	40.	.328	.337	
! I	50.	8.	40.	.336		
! N	60.	8.	40.	.346		
! G	70.	8.	40.	.357		
!	80.	8.	40.	.369		
----------	90.	8.	40.	.383	--------------	.387
! O	100.	8.	40.	.397		
! P	110.	8.	40.	.410		
! E	120.	8.	40.	.424		
! N	130.	8.	40.	.436	.436	
! I	140.	8.	40.	.447		
! N	150.	8.	40.	.456		
! G	160.	8.	40.	.463		
!	170.	8.	40.	.467		
CHASE	180.	8.	40.	.469		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15 N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG TIME TO INTERCEPT (QUADRANT) (HRS)	AVG TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	10.	16.	.577		
! C	10.	10.	16.	.582		
! L	20.	10.	16.	.599		
! O	30.	10.	16.	.629		
! S	40.	10.	16.	.672	.763	
! I	50.	10.	16.	.733		
! N	60.	10.	16.	.813		
! G	70.	10.	16.	.916		
!	80.	10.	16.	1.046		
----------	90.	10.	16.	1.201	--------------	1.375
! O	100.	10.	16.	1.379		
! P	110.	10.	16.	1.574		
! E	120.	10.	16.	1.774		
! N	130.	10.	16.	1.969	1.987	
! I	140.	10.	16.	2.145		
! N	150.	10.	16.	2.294		
! G	160.	10.	16.	2.406		
	170.	10.	16.	2.476		
CHASE	190.	10.	16.	2.500		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15.N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	10.	20.	.500		
! C	10.	10.	20.	.504		
! L	20.	10.	20.	.515		
! O	30.	10.	20.	.535		
! S	40.	10.	20.	.564	.616	
! I	50.	10.	20.	.602		
! N	60.	10.	20.	.651		
! G	70.	10.	20.	.712		
!	80.	10.	20.	.784		
----------	90.	10.	20.	.866	--------------	.934
! O	100.	10.	20.	.957		
! P	110.	10.	20.	1.054		
! E	120.	10.	20.	1.151		
! N	130.	10.	20.	1.245	1.253	
! I	140.	10.	20.	1.330		
! N	150.	10.	20.	1.401		
! G	160.	10.	20.	1.455		
!	170.	10.	20.	1.489		
CHASE	180.	10.	20.	1.500		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15.N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	10.	30.	.375		
! C	10.	10.	30.	.377		
! L	20.	10.	30.	.383		
! O	30.	10.	30.	.392		
! S	40.	10.	30.	.406	.427	
! I	50.	10.	30.	.423		
! N	60.	10.	30.	.445		
! G	70.	10.	30.	.470		
!	80.	10.	30.	.499		
----------	90.	10.	30.	.530	--------------	.547
! O	100.	10.	30.	.564		
! P	110.	10.	30.	.598		
! E	120.	10.	30.	.632		
! N	130.	10.	30.	.664	.666	
! I	140.	10.	30.	.693		
! N	150.	10.	30.	.717		
! G	160.	10.	30.	.735		
!	170.	10.	30.	.746		
CHASE	180.	10.	30.	.750		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15.N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	10.	40.	.300		
! C	10.	10.	40.	.301		
! L	20.	10.	40.	.305		
! O	30.	10.	40.	.310		
! S	40.	10.	40.	.318	.330	
! I	50.	10.	40.	.328		
! N	60.	10.	40.	.341		
! G	70.	10.	40.	.355		
!	80.	10.	40.	.370		
----------	90.	10.	40.	.387	--------------	.394
! O	100.	10.	40.	.405		
! P	110.	10.	40.	.423		
! E	120.	10.	40.	.441		
! N	130.	10.	40.	.457	.457	
! I	140.	10.	40.	.471		
! N	150.	10.	40.	.483		
! G	160.	10.	40.	.493		
!	170.	10.	40.	.498		
CHASE	180.	10.	40.	.500		

DATE 1 5 1983 TIME 16 21 35

DETECTION AT 15.N.MI. (SWEEP WIDTH = 30.N.MI.)
(EVADER HEADING W.R.T. INITIAL DETECTION VECTOR)

	EVADER HEADING (DEGS)	EVADER SPEED (KTS)	PURSUER SPEED (KTS)	TIME TO INTERCEPT (HRS)	AVG. TIME TO INTERCEPT (QUADRANT) (HRS)	AVG. TIME TO INTERCEPT (OVERALL) (HRS)
HEAD ON	0.	12.	16.	.536		
! C	10.	12.	16.	.542		
! L	20.	12.	16.	.561		
! O	30.	12.	16.	.595		
! S	40.	12.	16.	.646	.776	
! I	50.	12.	16.	.721		
! N	60.	12.	16.	.826		
! G	70.	12.	16.	.971		
!	80.	12.	16.	1.166		
----------	90.	12.	16.	1.417	--------------	1.799
! O	100.	12.	16.	1.724		
! P	110.	12.	16.	2.070		
! E	120.	12.	16.	2.433		
! N	130.	12.	16.	2.787	2.822	
! I	140.	12.	16.	3.109		
! N	150.	12.	16.	3.378		
! G	160.	12.	16.	3.581		
!	170.	12.	16.	3.707		
CHASE	180.	12.	16.	3.750		

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