Report No. CG-D-03-96

LAW ENFORCEMENT SIMULATION MODEL (LESIM)

A Support Tool for Planners and Decision Makers

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FINAL REPORT
October 1995

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National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Office of Engineering, Logistics, and Development
Washington, DC 20593-0001

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-03-96		

4. Title and Subtitle	5. Report Date
LAW ENFORCEMENT SIMULATION MODEL (LESIM) A Support Tool for Planners and Decision Makers	October 1995
	6. Performing Organization Code
7. Author(s) Kevin J. Cavanaugh, Christopher M. Rodriguez, Kevin F. Downer	8. Performing Organization Report No. R&DC 37/95
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Department of Transportation U.S. Coast Guard Office of Engineering, Logistics, and Development Washington, D.C. 20593-0001 Department of Transportation U.S. Coast Guard Office of Law Enforcement and Defense Operations Washington, D.C. 20593-0001	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

R&DC technical point of contact: Mr. Kevin F. Downer, (860) 441-2654

16. Abstract

This document provides an overview of LESIM, a discrete event simulation model of maritime law enforcement activities, as conducted by the Coast Guard. The purpose of LESIM is to provide planners and decision makers with a way to compare resource allocation alternatives in strategic and tactical planning, as well as to measure the potential effect of capability enhancement on mission performance. The report includes a description of the technical components of the model, and the types of problems for which the model can provide decision support. A review of the validation and verification process conducted is given, including four representative analyses performed to demonstrate the applicability and appropriateness of the model. Limitations of the model and potential improvements to it are identified.

17. Key Words	18. Distribution Statement
law enforcement simulation operations research resource allocation mission analysis	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

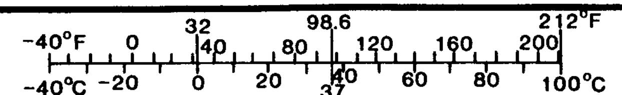
Approximate Conversions to Metric Measures

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).

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



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ACKNOWLEDGMENT

The Law Enforcement Simulation Model project came into being largely as a result of the vision, insight and perseverance of Mr. Joseph Walter Smith. The project manager from its inception until he passed away in July, 1993, Mr. Smith was one of the first to see the potential of applying operations research tools to Coast Guard problems. Without his dedication, intelligence and hard work, this model would not have been possible.

INTRODUCTION

The U.S. Coast Guard is the premier maritime law enforcement agency in the United States. It is charged by statute to enforce all applicable Federal laws on, under and over the high seas and waters subject to the jurisdiction of the United States, and to engage in surveillance or interdiction to enforce these laws. In order to carry out these duties, Coast Guard cutters and aircraft perform law enforcement patrols: monitoring vessel traffic, making inquiries and examinations of contacted vessels, conducting boardings to ensure compliance with the laws, and, when appropriate, making seizures and arrests of violators.

As in most law enforcement arenas, the Coast Guard's law enforcement mission is conducted in an atmosphere of uncertainty. Offenders do not share their plans and schedules with law enforcement officials. Illegal activity is often difficult to detect, and most violators are indistinguishable from legitimate maritime traffic without careful, close inspection. As a result, decisions as to resource allocation have historically been made based on instinct, experience and the analysis of available intelligence data. This approach, the best available until now, provided good results but had several important drawbacks. Decisions based on this approach are difficult to defend to external auditors and oversight groups. The decision logic is highly individualized and generally not documented, so similar situations may not be recognized, and comparisons of various courses of action cannot be made. Finally, decision makers are sometimes called upon to extrapolate into areas where there experience is limited, in fact, into completely new areas in which no one is experienced.

With the advent of computer simulation, the possibility of deciding where to assign available law enforcement resources based on quantitative analysis of several alternatives has arisen. Computer simulation offers three significant strengths in this type of analysis:

- Performance measurement is easier. Since the total number of violators in the simulation is known, the percentage of violators detected, identified and seized can be measured. This is not true in the real world environment.
- The uncertainty inherent in the actual environment can be modeled easily and effectively.
- Computer simulation models allow for statistical inference. In the real world, the variation in output measures from one time period to another is caused by changes in so many different factors that attributing changes in the measures to any single input factor, or set of factors, is very difficult.

The Coast Guard Research & Development Center was tasked with investigating the possible uses of computer simulation in making resource allocation decisions for maritime law enforcement. The result of this tasking is the law enforcement simulation, LESIM -- a discrete event simulation model with an artificial intelligence component. LESIM was developed in cooperation with the Artificial Intelligence Laboratory at Arizona State University. It uses a knowledge base, developed through interviews with Coast Guard operations experts, to support a plan generator for making resource allocation and cutter routing decisions. LESIM is designed to model Coast Guard assets at the district level engaged in the inspection and interdiction of marine traffic. It incorporates realistic cutter schedules provided by the user, or an optimal schedule generated by an external program[1]. The assets modeled in LESIM include cutters and patrol boats of all classes, cutters with organic helicopters, US Navy vessels, and fixed-wing aircraft. The model also accommodates special missions such as search and rescue (SAR) and air dropped drug smuggling activities. All of the simulated activities occur in a computer environment that includes a realistic district geography (coast lines, ports, and islands) and a weather model that can imitate changing sea conditions and visibility.

The primary purpose of LESIM is to provide planners and decision makers with a way of comparing resource allocation alternatives. LESIM may also be used for various forms of strategic and tactical planning. It is a tool that is capable of testing cutter schedules, as well as measuring the effectiveness of different resource mixes engaged in law enforcement activities. If the right blend of personnel is trained to use and maintain the model, it has the potential for being an invaluable asset for testing and evaluating cutter capability enhancements and any tactical alternatives related to those enhancements.

This report provides an overview of LESIM, beginning with an introduction to its five technical components. Next, the types of problems for which LESIM can provide decision support are described, as is the interface for setting up these problems. A description of the process used to validate and verify the simulation is given, including high level descriptions of four analyses already conducted using LESIM. Finally, the limitations of LESIM, as well as some potential enhancements, are discussed. Most of the above items are described in greater detail in other documents, which are referenced throughout this report.

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[1] "SEVENTH DISTRICT CUTTER SCHEDULING, by Dr. Robert F. Dell, Naval Postgraduate School. This optimization model, which is listed in Appendix C, minimizes the difference between a desired patrol schedule and the actual one, given resource and time constraints.

2.0 TECHNICAL OVERVIEW

The following subsections provide a general overview of the main components of LESIM. A detailed description of the system components is provided in Appendix A.

2.1 Resource Model

To perform its law enforcement mission, the Coast Guard dispatches cutters (surface vessels), and aircraft to search for, intercept, board and seize vessels in violation of federal laws. The assets available to the Coast Guard for the inspection and interdiction of marine traffic form the resource model within the simulation. All cutters, patrol boats, and Navy ships are modeled as permanent entities. Each resource entity has static and dynamic attributes assigned to it in order to define capabilities, monitor status, and control operations. Resource entities may also own sets, which are organized collections of other entities. Some examples of static resource attributes would be things such as maximum speed, range of the surface search radar, and fuel capacity. Examples of dynamic resource attributes include, the amount of fuel remaining, current location, and time spent on the current mission. Other assets, such as helicopters and fixed-wing aircraft are modeled in a simpler fashion.

The helicopter resources are not modeled as true entities like cutters and patrol boats. They are represented in the model as an augmented capability of a cutter resource that is equipped to carry a helicopter onboard. LESIM was first envisioned as a simulation of surface interactions alone. The helicopters do not exist independently of cutters. The increase in fidelity gained by modeling helicopters as independent entities was deemed unjustified, in relation to the expense and time necessary to achieve it. The helicopter essentially acts as an extension of the cutter's radar detection range and increases the rate at which a cutter is able to identify and sort marine traffic. This approach, while somewhat limiting, is adequate for most resource allocation or capability enhancement questions.

2.2 Traffic Model

The traffic model simulates the arrival and departure of marine vessels, other than those used by the Coast Guard. It creates the traffic vessel entities (called suspects) and generates their attributes and characteristics following a user-defined probability distribution. The entities are then supplied to the activity manager, which simulates traffic movement and process interactions.

Table 1. Marine Vessel Characteristics

TYPE	SIZE	SUSPICION LEVEL	SEIZURE INDICATOR
Merchant	Small	1 (low)	Non-seizable
Fishing	Medium	2	Seizable
Power (Recreational)	Large	3	
Sail		4	
Other		5 (high)	

As shown in Table 1, there are five types of vessels used in the model. The types are merchant, power, fishing, sail, and other (a general category for vessels not covered by the four previous types). For each vessel type there are three size classifications, small, medium and large. All traffic is assigned a suspicion level from 1 to 5, 1 being not suspicious and 5 being highly suspicious. This is done to provide the model with a criterion for choosing between contacts when deciding which ones to interdict for boarding, and to simulate the ability of Coast Guard personnel to 'sort' suspect traffic correctly. In other words, it models the many indicators that cause a cutter Commanding Officer to choose to pursue one vessel over another. The suspicion level of a contact becomes known to Coast Guard resources when the contact is visually identified. Violation indicator specifies whether or not the vessel is committing a seizable offense. The value of this indicator is not known to any Coast Guard resources until the vessel is boarded.

The distribution of any particular arrangement of traffic vessels, with respect to their characteristics, is provided as user input, and can easily be modified through data files. Each vessel is assigned to a route running through a user defined corridor that specifies the bounds for traffic flow through the model. The edges of the corridors are shown as dashed lines on the map in Figure 1, and the general direction of traffic flow is shown by the arrows. The exact route is a set of way points picked randomly from within the corridor. The corridor a vessel will transit is selected according to the vessel's type and size.

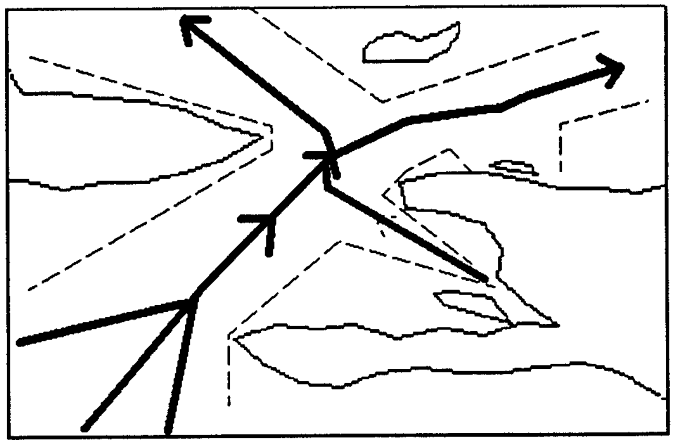

Figure 1. Traffic Corridor

2.3 Plan Generator

The plan generator (PG) models the role of an intelligent decision-making agent in the LESIM system. In the real world, it corresponds to the operational commander, deciding which resource to apply to which events. It is activated when an event occurring in the simulation requires a resource selection decision or route planning. As soon as the event occurs, the simulation performs an "interrupt" and suspends itself. The simulation then conveys all the necessary information about the state of the world to the PG for analysis. After analyzing the information, the PG makes a decision and conveys it back to the simulation.

The rule-based planner models the process of resource selection used by the Coast Guard in selecting a resource to investigate a contact. It also selects resources for patrol tactics in OPAREAs, selects resources for SAR and air dropped drug missions, and does all required route planning.

2.4 Environmental Model

This component provides the weather conditions used in simulating resource and traffic movements and the geography relevant to the District or area being modeled. The weather consists of two factors: wave height and visibility. The weather affects resource and traffic vessel movements, as well as traffic generation. The changes in visibility and wave height are modeled as a Markov chain, based on distributions obtained by the USCG from the National Oceanic and Atmospheric Administration (NOAA). The geography is implemented as a set of polygons representing coastal areas and islands. The geography is used to establish the location of ports, choke points, and navigable water.

2.5 Activity Manager

The activity manager is the core of the simulation. This component manages the activities of resources and traffic as well as the interactions between them. The functions that the activity manager performs are:

- Scheduling resource entries and exits as determined by external schedules.
- Coordinating resource and traffic movements.
- Monitoring interactions between resources and traffic.
- Communicating with the plan generator.
- Modeling the results of air surveillance.
- Scheduling and responding to search and rescue events.
- Scheduling and responding to air drop drug smuggling events.

2.5.1 Air Surveillance Model

This facet of the Activity Manager simulates fixed wing air coverage of district OPAREAs. There are no active aircraft entities used in LESIM. Air surveillance is modeled in a simplified fashion based upon a probability of detection of vessel traffic by an aircraft. The probability of detection for an oparea is user-defined, based on the expected coverage of the area by fixed-wing aircraft. When a vessel enters an oparea, a random draw is taken to determine if the vessel is spotted. If it is, its location, course, speed and suspicion level are passed to the plan generator, which assigns a resource to interdict it, if appropriate.

2.5.2 Search and Rescue Model

Coast Guard policy is to interrupt law enforcement tasks whenever a life-threatening search and rescue (SAR) case occurs within the response radius of a resource. The result of this policy is modeled in LESIM by having resources that are normally available for law enforcement purposes be preempted and allocated to the SAR task for some period of time. The purpose of this is to more accurately model the availability of the resource to perform law enforcement functions, rather than to accurately simulate the SAR mission. The length of time is chosen so that it is typical of SAR cases in the area, and it varies from case to case. In selecting resources for a SAR mission the plan generator gives higher priority to vessels that are not engaged in important tasks (e.g., interceptions, boardings). However, preemptions may occur for life threatening SAR cases. Each SAR case is created with the characteristics shown in Table 2.

Table 2. SAR Case Attributes

Attribute	Possible Values
Type	Life Threatening (LT) or Non-Life-Threatening (NLT)
Size of distressed vessel	Small, Medium, Large
Location	Oparea ID
Delay	Time to prosecute the SAR case

The distribution of the SAR cases, with respect to these characteristics, is provided as user input, and can be determined from information read in from a data file created using an appropriate SAR data base. The type characteristic determines whether a law enforcement resource will be preempted from a critical task in order to respond; the size and the location of the distressed vessel determine what resources are potential response units.

2.5.3 Air Drop Model

Air drop cases are drug smuggling incidents in which contraband is dropped from a low-flying aircraft to accomplices in boats. In LESIM, air drop cases are handled similarly to SAR cases except they have different characteristics. Air drop events occur randomly, based on the following:

- A distribution of air drop event duration (including lead time, search time, and processing time) is developed based on user input.
- Air drop locations are randomly chosen from a set of user defined areas.
- Frequency of air drop events (events per year) is defined by the user.

If any available cutters (not engaged in a boarding, interdiction of a highly suspicious contact or a life threatening SAR case) are within a user defined transit time threshold of the location of the air drop, the closest cutter is placed in AIRDROP status (from which it may only be called to respond to life threatening SAR cases) and transits to the location determined for the air drop mission. It remains on scene for a random period of time, then returns to its patrol tactic.

3.0 LESIM's PROBLEM DOMAIN AND USER INTERFACE

In this section, the application of LESIM as a decision support tool is discussed. Some of the user interface issues are reviewed, and a brief description of the front-end graphic interface is given. Then, a description is given of two types of problems LESIM is suited for: resource allocation problems and capability improvement problems. Examples of these types of problems are given in Section 4.

3.1 The LESIM User Interface

Within the LESIM model, a "scenario" is a particular arrangement of Coast Guard resources, cutter and aircraft schedules, tactics, threat distribution, and threat level. All scenarios are developed by modifying LESIM input files. Modification of data files is the only means to create different scenarios for testing without making changes to the code. These files can be modified in one of two ways. All of the input data files are ASCII text files, and can be changed using a text editor. Since these files follow strict format rules, however, a friendlier interface was developed to facilitate data file changes.

The current user interface is a Microsoft Excel 5.0 application named the LESIM User Interface[2]. The LESIM User Interface is an Excel workbook (multiple spreadsheets grouped into a single unit) with macros. The User Interface runs on a Windows-based PC, and creates data files for transfer to the VAX/VMS system. The macros are linked to objects such as list boxes, buttons, and icons that perform specific functions when selected. The four main sections of the User Interface are:

- User Options
- Finding and Modifying LESIM Data Files
- LESIM Data Files
- Running LESIM on the VAX

3.1.2 LESIM Configuration and Execution

LESIM is designed to take advantage of the processing power of computer workstations such as the VAXstation 3100, and inexpensive analysis and data management tools available for the personal computer (PC). This arrangement provides an incredible amount of flexibility in the types of analyses that can be performed and helps to enhance the communication of results. Figure 2 shows the LESIM system, a combination of the simulation model residing on the VAX workstations and PC based analysis and data management tools. They are linked together through Digital Equipment Company's Pathworks Version 4.1 network software.

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[2] Downer, Kevin, LESIM User Interface, USCG R&D Center, 1995.

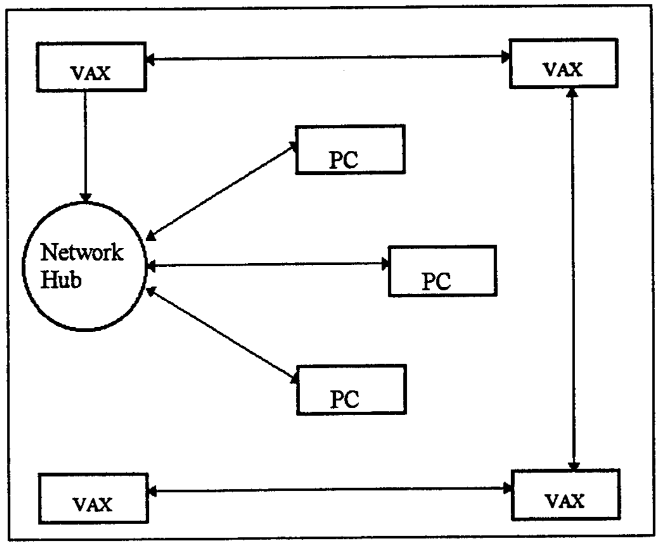

Figure 2. LESIM System Configuration

3.2 Resource Allocation Problems

LESIM provides the Coast Guard decision maker with a quantitative tool to assist in making decisions on resource allocation problems. There are many factors to consider when allocating scarce resources to perform a Coast Guard mission such as law enforcement. Some of these are the speed and endurance of the available resources, sea-keeping ability, the number of boarding parties available, the number of threat vessels encountered, the geographical makeup of the OPAREA, weather, natural chokepoints, ability to support helicopters, ability to work with fixed wing assets, intelligence reports, and the ability to escort seized vessels. Because of the large number of factors it is difficult for a human decision maker to reach a decision that optimizes the results obtained, without some type of analytical tool to assist in the process. LESIM allows the decision maker to take many of these factors into account to see how they affect the outcome of the mission or selected performance criteria. Armed with this additional insight, the decision maker can incorporate past experience, judgment, and other pertinent data to come to an analytically based, logical decision.

One type of problem LESIM can be applied to is the resource allocation problem. This class of problems addresses questions like:

(1) What resources should be used for a particular mission or objective? For example, if a district commander has two WMEC's and three WPB's available to perform LE operations, LESIM can assist in determining which combination of resources is most effective and efficient at interdicting, boarding, and seizing vessels. Various combinations of vessels can be compared directly, on several different performance criteria. The cost of each alternative can be estimated using standard rates, and comparisons can be made between performance and costs.

(2) Where should resources be positioned during patrols, and where should they be homeported for maximum effectiveness? Not only is it important to determine which

resources should be working together, but also where they should concentrate their time patrolling. In areas where the threat vessels transit through a natural chokepoint such as the Yucatan Pass, such decisions are fairly obvious. However, in areas without chokepoints, LESIM allows the decision maker to experiment with patrol locations for various resources and to determine the corresponding effect on mission performance. Since traffic patterns and smuggling routes are not known in advance, the performance of patrolling resources against different potential patterns can be measured.

(3) ***What is the best schedule for a set of resources to perform a mission most effectively over a protracted time period?*** Combined with the GAMS scheduling model written by the Naval Postgraduate School, LESIM can be used to determine the best combination of resources and the operations schedule to use to perform a given mission most effectively. Several scheduling options can be designed and then tested against one another to determine which results in the best performance.

(4) ***How many aircraft should be used with surface resources? Should they be deployed or operate from an air station?*** The use of aircraft to assist surface resources in performing LE missions can be explored using LESIM. At times it may be more cost-effective to perform a given mission with or without an assigned helicopter. Perhaps using another cutter, such as a WPB, may be more appropriate depending on the objective of the mission. If intelligence gathering is the most important mission objective, maximum use of aircraft may be desired to obtain the most number of sightings. On the other hand, if interdiction is the primary mission objective, the combination of resources that results in the greatest number of boardings may be preferred. Supporting LE operations from a nearby air station may be more efficient than assigning a helicopter to a cutter. LESIM allows the decision maker to test different combinations of resources, including options with aircraft, to determine which scenario best accomplishes the desired goal.

(5) ***What type of operational doctrine should the resources follow for maximum mission effectiveness?*** LESIM can be used to compare different tactical operating procedures to determine which most effectively accomplishes the mission, for example, changes in the shape of patrol patterns such as using a creeping line search pattern versus a barrier patrol tactic. It can be used to compare scenarios in which a cutter interdicts vessels at different speeds to determine the effect of cutter speed on LE mission performance.

3.3 Capability Enhancement Problems

The resources available to perform the LE missions are constantly changing. New technology often results in faster and more capable vessels, improved communications, better intelligence gathering devices, improved radar, and a never ending series of improvements to the tools that are used to perform the mission. The effect of these improvements on the performance of the mission is often difficult to quantify. LESIM can help determine the effects of improved or changed resource capabilities. The simulation allows theoretical systems to be compared to current systems in a controlled environment to determine what, if any, improvements in performance can be gained, and if it is worth investing in the proposed capability enhancement. Most capability enhancements that directly affect the operational characteristics of the resource while performing the mission can be modeled. Several examples of types of problems that LESIM can assist in answering include:

(1) If a cutter's speed capability is increased by 5 knots will LE performance improve and, if so, by how much? If LE performance does improve, is it worth the investment?

(2) What is the effect on LE mission performance of replacing an AN-SPS64 conventional radar with an APS-137? Is it worth the investment?

(3) What will be the expected LE performance increase from a proposed new cutter or aircraft acquisition? The theoretical performance capabilities of the new platforms can be modeled by LESIM to provide an estimate of the marginal increase in performance vs cost curve.

(4) How does a new detection capability (e.g., using an aerostat) affect the performance of the mission?

(5) Changes in organizational capabilities can also be explored. For example, the effects of a new LE related policy on LE mission performance can be estimated prior to actually adopting the policy. Potential problems with the policy can be identified and corrected prior to causing any logistical problems in the field. For example, if a new LE policy was expected to result in the seizures of more vessels than usual, LESIM could be used to determine how much additional time cutters would spend escorting vessels to port and to determine the number of UTB's or WPB's needed to receive vessels handed off by WMEC's and WHEC's.

LESIM can also be used to determine if a proposed capability enhancement project is worth pursuing before it is even developed. The theoretical capabilities of the new system can be tested in the LESIM environment to determine what the potential benefits are. Then the benefits can be compared to the development cost of the enhancement to determine if it is a cost effective strategy. Along the same lines, LESIM may be used to allocate limited funds for R&D efforts to improve resource capabilities. Many different proposed projects for capability enhancement can be experimented with and compared to a standard to find out which one will give the most performance improvement. The projects with the greatest potential performance improvement would be the ones in which to invest development resources.

4.0 VALIDATION AND VERIFICATION PROCESS

The validation and verification processes are designed to ensure that a simulation model is "modeling the right things right". The validation process examines the conceptual model and confirms that the modelers have accurately depicted the real world system, to the degree of fidelity required. In the verification process, the actual software realization of the conceptual model is reviewed, to guard against bugs, miscoding and improper implementation. Each of these processes, as they pertain to LESIM, is described below.

4.1 Conceptual Model Validation

Validation is the judgment that the model examined is suitably accurate to support the decisions within the model's problem domain. It involves evaluation of the model by:

- examining the conceptual model, the underlying assumptions and methodologies used to construct the computer program;
- submodel testing, examining the model outcomes in a set of tests which have predictable outcomes; and
- results validation, comparing the model's outcomes to data collected from the real system.[3]

The conceptual model for LESIM was developed and reviewed in a series of workshops involving modelers and end-users at both the Headquarters and District levels. The end users involved in these workshops had extensive experience performing the types of operations LESIM simulates. The workshops consisted largely of "structured walk-throughs" of the event procedures and logic of the LESIM code, and ensured that the conceptual model had a high degree of face validity.

With the introduction of animation for the LESIM output, validation of the conceptual model was made even easier. Visualization of the inner workings of the simulation is now possible, and this feature was used repeatedly in briefings and presentations to high-level decision makers, end-user analysts and technical personnel.

Finally, the simulation was used to conduct experiments that formed the basis for a series of four sample analyses. These analyses, which are described in Section 4.3, served two purposes. The first was to provide useful information to the sponsor and the end-user. The second was to demonstrate that the results obtained by using LESIM were consistent with real world observations, further validating the conceptual model and its implementation.

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[3] Bailey, Michael & Dell, Robert, LESIM VALIDATION AND ACCREDITATION REPORT, Naval Postgraduate School, Monterey, CA, 28 March 1995.

4.2 Results Validation

One of the most difficult methods of validating a simulation model is by comparing the output of the simulation to the output of the real system. Although this approach has an intuitive appeal, in anything but the simplest system, it is filled with difficulties. The reason for this is that both the simulation and the real system are stochastic in nature -- they are random processes. In both systems, the same input does not always result in the same output, due to random fluctuations. If it is possible to produce many iterations of each system, so that the distribution of the outcome produced by any given input can be estimated, then the distribution for both the real system and the simulation should be similar. More precisely, they should be able to pass statistical tests that the two systems are equivalent.

In the case of a system such as the one LESIM simulates, it is impossible to reproduce the exact inputs to the real system (traffic, cutter schedules, vessel locations, etc.), so that the distribution of the real system outputs can be determined as a function of the inputs. As a result, the output of the simulated system, averaged over many replications, must be compared to the output from a single instance of the real system. Of course, each of these systems produces several output measures, and all of them can be compared, but the desired result is only that most of the results from the simulation be "reasonably" close to those of the real system.

In order to compare the results of LESIM to the real world system, the following data, pertaining to a single quarter of Coast Guard operations in the seventh district, were obtained: cutter schedules for all cutters in the seventh district AOR, number of boardings conducted, number of seizures, and number of vessels identified in 4 of the 10 LESIM opareas, and number of boardings and seizures for the combined Key West/Bahamas LESIM Oparea. The cutter schedules were fixed, and the inputs controlling threat traffic (amount, type, size, suspicion level and violation indicator) were manipulated in order to bring the simulation output as close as possible to the real world figures. The results shown in Table 3 were obtained.

Table 3. Comparison of Simulation and Real System Output

OPAREA	Identified			Boarded			Seized		
	LESIM	Actual	% Diff.	LESIM	Actual	% Diff.	LESIM	Actual	% Diff.
Windward	617	653	-5.5%	28	41	-30.6%	0.23	0	
GANTSEC	1379	1246	10.7%	138	152	-9.1%	0.57	4	-85.8%
Caribbean	5507	5710	-3.6%	229	187	22.5%	2.70	0	
Yucatan	286	270	6.0%	22	9	147.8%	0.07	2	-96.7%
Key West, Miami				130	181	-28.0%	2.13	0	
TOTAL	7790	7879	-1.1%	548	570	-3.8%	5.70	6	-5.0%

Note that activity in the Yucatan seems different from other OPAREAs. The number of boardings and the ratio of boardings to vessels identified are both lower than in most other opareas, yet this oparea accounted for two-thirds of the actual seizure in this quarter. This supports the idea that law enforcement activity in the Yucatan was highly intelligence driven during this quarter, i.e., specific targets were sought, found, boarded and seized, and other potential targets were largely ignored. At the current time, LESIM does not have the capability to model a law enforcement mission as selective as this one is, concurrently with an area patrol mission.

The above results from LESIM are the average of 30 replications of a complete quarter of Coast Guard operations in the 7th district AOR. The same cutter schedule was used in each replication, which means that the same cutters were available for patrol during the appropriate time periods. Actual location and activity of the cutters, however, are determined by the random interactions between the cutters and the threat traffic. There were 31,000 vessels created to transit the AOR in each replication, and, because of the length of simulated time (92 days) and the number of vessel interactions, each replication took approximately 12 hours to run.

The results obtained for both the number of vessels identified and the number boarded were very close to the actual figures for this same time period. The process of refining the inputs to produce reasonably close outputs was designed to minimize the difference between the total output measures first, and only then try to apportion the outputs between the opareas correctly. It is possible, therefore, to match any of the individual oparea results more closely by further manipulations of the inputs. Generally, however, this is at a cost of degrading the global performance.

While the total number of seizures obtained for the entire district is close to the actual number of seizures during this time period, the seizures in the simulation model occurred in different places than those in the actual system. With such a small number of seizures occurring, this is not alarming. Without undue manipulation, the LESIM operator cannot directly control the route taken by a smuggling vessel. The overall level of seizures can be controlled by changing the percentage of vessels carrying contraband. A higher percentage of seizable vessels, and the same number of boardings, results in a higher number of seizures. The above results are reasonably close to the actual system outputs, and suggest that LESIM accurately reflects the real world it simulates.

4.3 Analyses Conducted

Four analyses were completed for the seventh Coast Guard district using LESIM. They included: An Analysis of Resource Allocation Decisions Using Simulation[4], An Analysis of Helicopter Resource Utilization Using Simulation[5], Measuring the Effects of Improved Radar Capability on Performance Using the Law Enforcement Simulation Model (LESIM)[6], and Determining the Effects of Boarding Intensity and Threat Level on Seizure Rates using Simulation[7]. The resource allocation analysis compared the law enforcement mission performance of eight different combinations of Coast Guard assets. The helicopter resource utilization analysis investigated the effects on LE mission performance with increased use of helicopter assets. The radar capability analysis compared the use of an APS-137 radar equipped cutter with a cutter using a conventional radar system and with a helicopter. The fourth analysis developed statistical models of the effects of changing boarding intensity and threat level on the seizure rates of eight different cutter and helo combinations.

Each analysis supported the law enforcement operations of the seventh district, and, at the same time, was a crucial part of the validation, verification and accreditation process for the LESIM model. In performing these studies, the capabilities and limitations of LESIM were explored. By simulating real Coast Guard problems we were able to determine more effectively if the model was operating properly. We were also concerned with determining whether or not LESIM was an accurate representation of the LE operations in the seventh district. Each analysis contributed to the validation process, determining if the model sufficiently represented the LE mission of the Coast Guard. Finally, the analyses helped illustrate the types of decision making processes that LESIM is capable of supporting for a Coast Guard manager.

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[4] An Analysis of Resource Allocation Decisions Using Simulation, LCDR Kevin Cavanaugh & LT Chris M. Rodriguez, USCG Research & Development Center, July 1994.

[5] An Analysis of Helicopter Resource Utilization Using Simulation, LT Chris M. Rodriguez & LCDR Kevin Cavanaugh, USCG Research & Development Center, July 1994.

[6] Measuring the Effects of Improved Radar Capability on Performance Using the Law Enforcement Simulation Model (LESIM), Kevin Downer & LCDR Kevin Cavanaugh, USCG Research & Development Center, January 1995.

[7] Determining the Effects of Boarding Intensity and Threat Level on Seizure Rates using Simulation, LT Chris M. Rodriguez & LCDR Kevin Cavanaugh, USCG Research & Development Center, July 1995.

These analyses serve as examples of the value that simulation can add to the management of program missions and to the test and evaluation process. Obviously, a final decision to acquire hardware or change operational doctrine should not be based on the results of simulation alone. However, simulation can be an inexpensive indicator of the magnitude of performance improvement that might be realized as a result of the use of new hardware or a new method of operations. LESIM has proven to be a flexible tool for understanding the Coast Guard's law enforcement mission. In its current form it can be used to:

- make resource allocation decisions
- experiment with tactical procedures for developing operational doctrine
- rapidly assist in formulating contingency plans for unexpected circumstances
- determine the effects of new hardware on LE performance
- develop new measures of effectiveness for the LE mission
- collect data to justify new acquisitions, and
- improve understanding of the variables that affect LE mission performance.

The four analyses conducted are briefly described in the next four sections. For a more detailed report on each analysis, consult the above listed references.

4.3.1 Resource Allocation

4.3.1.1 Objective

The Resource Allocation Analysis used LESIM to compare the law enforcement performance of various combinations of CG assets operating in the Yucatan Peninsula OPAREA. The purpose of the study was to demonstrate the support that LESIM can provide to an operational commander in making the best resource allocation decisions for a variety of objectives. The way to define 'best' in this context depends on the objective of the operational commander or decision maker. No single measure of effectiveness is adequate for determining effective performance of the drug interdiction mission. As a result, different resource combinations could be interpreted as best, depending on the desired objective.

4.3.1.2 Description of Analysis

To compare the performance of different resources, eight different combinations of two WMEC's and two HH-65's were employed in the same oparea (the Yucatan Peninsula), using the same traffic patterns and composition. In each case, the cutters and aircraft will follow the same decision rules in choosing the course of action to follow when presented with the same situation, so the differences in performance are all attributable to the difference in capability between combinations. Codes used for each combination are given in Table 4.

Table 4. Scenario Descriptions

Code	Description
210	One 210 (homeported in Key West)
270	One 270 (homeported in Key West)
210H	210 with an HH65
270H	270 with an HH65
210_270	210 and 270 together without helos
210H270	210 with HH65 and a 270
270H210	270 with HH65 and a 210
210H270H	210 with HH65 and 270 with HH65

The experiment consisted of a simulated 23 day patrol in the Yucatan Strait, during which 263 "threat" vessels transited through the area. Each cutter on patrol followed a barrier patrol tactic. When no active contacts were held, the cutter followed a rectangular trackline (60nm x 10nm) spanning the Yucatan. When contacts were detected, the cutter left its' patrol trackline, intercepted the contact, boarded it if appropriate, then either intercepted another contact, if one was available, or returned to its trackline.

The performance measures used for comparison were:

- percentage of contraband-carrying vessels detected and seized
- percentage of time a cutter spends actually boarding, and
- fraction of boardings which result in seizure.

4.3.1.3 Summary of Results

In comparing alternative resource mixes, the choice of performance measures, or measures of effectiveness, can lead to very different decisions. If seizure rate is selected as the primary measure, then the appropriate activity would be to maximize boardings, since seizure rate and number of boardings were found to be positively correlated. The two-cutter scenarios had the highest boarding and seizure rates. The price for this improved seizure rate, however, is that the two cutters are not fully utilized. The single cutter in the 270H scenario spends more time conducting boardings than either of the two cutters in the 210H270 or 270H210 scenarios. Choosing the 270-helo combination is a much more efficient use of resources, which enables the reassignment of the other cutter resource elsewhere. This difference appeared to be highly dependent on the traffic level, a result explored in more depth in the boarding intensity and traffic level analysis, which is discussed in section 4.3.3.

In this particular experiment, the combinations of two cutters with at least one helo maximized the percentage of seizable vessels seized, as shown in Figure 3. Defining the 'best' resource allocation decision in this way, the operational commander should not assign a helicopter to both cutters, since the performance of the two-cutter, two-helicopter combination was no better than the two-cutter, single helicopter scenarios.

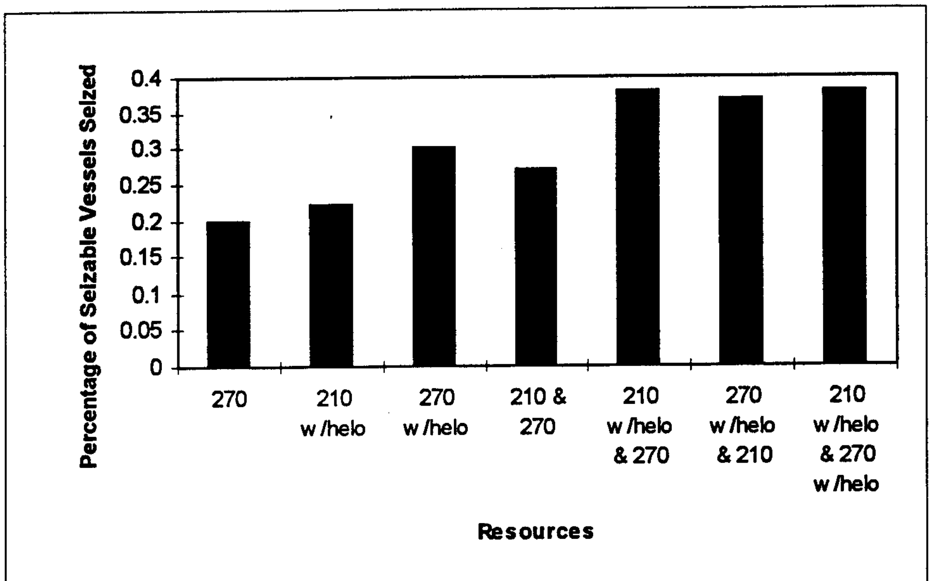

Figure 3. Comparison of Different Resource Combinations

On the other hand, the single cutter scenarios have the advantage that the resources are more fully utilized. Figure 4 shows that all of the single cutter allocations spent more of their on scene time actually performing boardings. A Coast Guard cutter is a high cost resource, and the main advantage of having a cutter on scene is to enable the placement of a boarding team on a vessel. If a patrolling cutter is spending a small portion of the time actually conducting boardings, then possibly that resource should be placed in a different oparea, where the need for it is more critical.

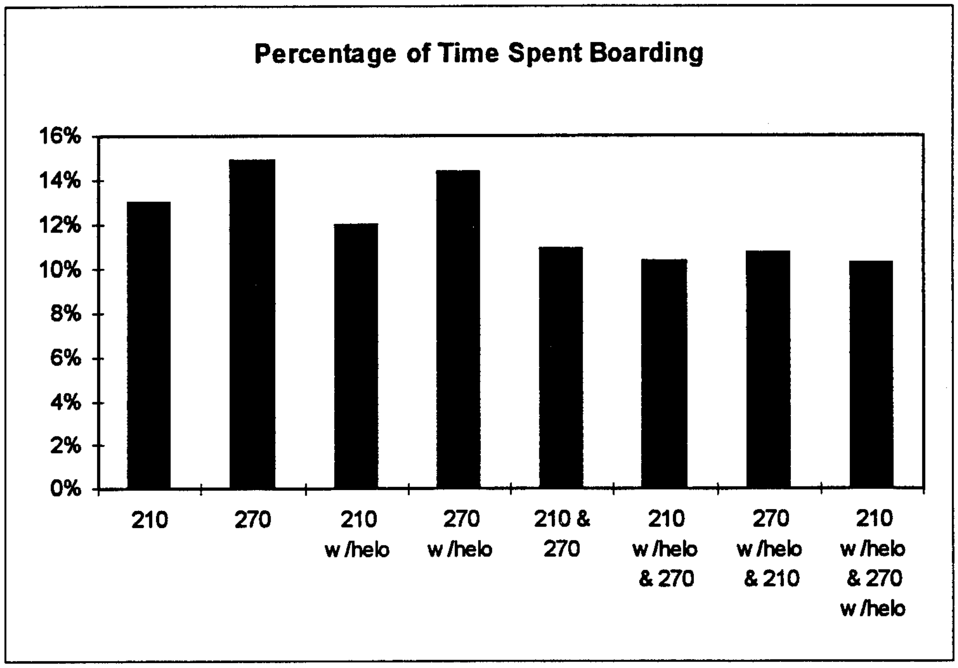

Figure 4. Percentage of Cutter Time Spent Boarding

The third performance measure investigated in this study was the fraction of boardings that resulted in seizures. In LESIM, cutters will board the most suspicious vessel they have identified, as long as its suspicion level is above the minimum threshold level. For a cutter acting alone, this is a simple yes or no decision - suspicion level is determined at the same time the vessel is identified, and the boarding decision is made on the spot. A cutter working with a helicopter, on the other hand, is presented with a slate of identified vessels to choose from, and will pursue the most suspicious of these. This should result in a higher seizure-to-boarding ratio, an indicator of efficiency in law enforcement operations. As can be seen in Figure 5, this reasoning is supported by experiment. The seizure to boarding ratio is lower for all the non-helicopter combinations. Helo-equipped cutters were able to board a larger percentage of high suspicion level vessels. This improved efficiency was explored further in the helo analysis paper.

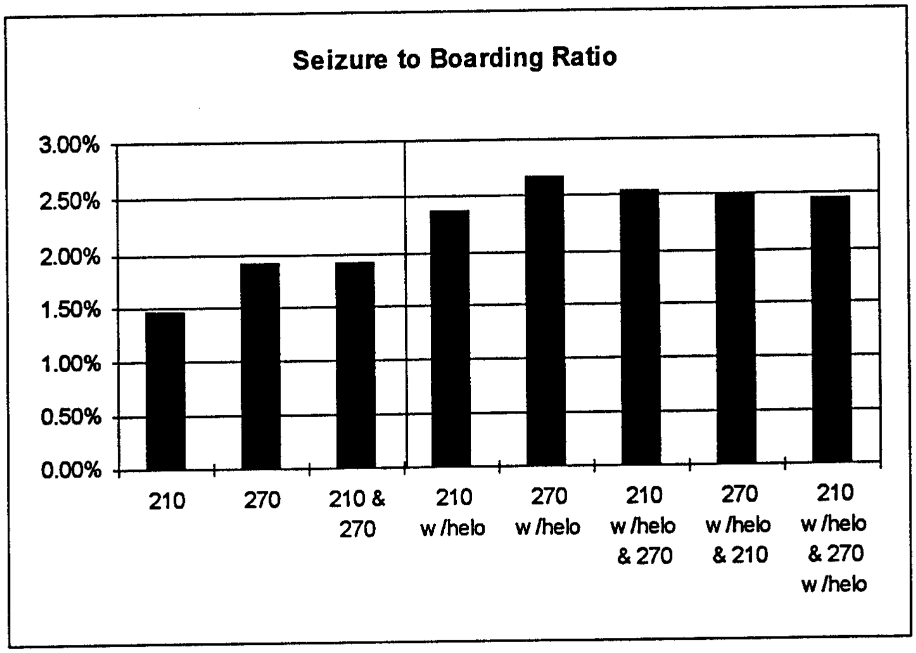

Figure 5. Seizure to Boarding Ratio

If goals for each performance measure are established, a combination can be selected which meets all the goals at a minimum cost. For example, if the goal for a certain time period is to detect at least 60% of all vessels in the Yucatan, have each cutter spend at least 15% of its time conducting boardings, and detect and seize 60% of all contraband-carrying vessels, then the 270H210 combination, 210H270 combination and 210H270H combination all meet the stated goals. Since the cost of both two-cutter, one-helo scenarios should be about the same, a choice can be made between these two options based either on some secondary performance measure, or on other considerations such as helo support capability.

4.3.2 Helicopter Resource Utilization

4.3.2.1 Objective

The Helicopter Resource Utilization Analysis used LESIM to measure the effects on law enforcement mission performance in the Yucatan Strait of increasing the number of helicopter hours available to a cutter. As in the Resource Allocation analysis, the purpose of the study was to demonstrate the support that LESIM can provide to an operational commander in making the best resource allocation decisions. In this case, the focus was on the benefits derived by using helicopters deployed aboard medium endurance cutters (WMEC's).

4.3.2.2 Description of Analysis

A period of operations spanning 97 days in the Yucatan Strait was examined, with the average Coast Guard presence in the OPAREA ranging from a single 210' WMEC operating without a helicopter, to two 210' WMEC's both operating with HH-65 helicopters attached. We focused on the effects of varying the amount of available helicopter hours on LE mission performance, boarding effectiveness, cutter utilization, and helicopter utilization. Helicopter hours were increased or decreased by controlling the number of days the helicopter was deployed onboard the cutter. In addition, the costs and cost/benefit of each alternative was considered to assist in decision making. The cutters worked together over a 97 day period to conduct a barrier patrol in the Yucatan Strait and encountered 2,785 "threat" vessels. The performance measures used for comparison were:

- percentage of all vessels detected by radar, visually identified, and boarded
- percentage of time a cutter spends actually boarding,
- percentage of contraband-carrying vessels detected and seized,
- fraction of boardings which result in seizure,
- the average suspicion level of the vessels boarded,
- the percentage of available flight hours actually flown,
- the average total resource cost, cost per performance measure, and cost per seizure.

In order to reach statistically significant conclusions, a large number of runs of the simulation were required. A total of 19 cutter and helicopter combinations (called scenarios) were compared. For each combination, 30 replications of that particular scenario were completed, varying the random portions according to the predetermined probability distributions. This provided enough data to determine the significance of differences in the output performance measures.

4.3.2.2 Summary of Results

This analysis supports the conventional wisdom that using helicopters improves general law enforcement performance. It quantitatively shows that increasing helo resources improves performance as measured by the fraction of all vessels detected and identified, as shown in Figure 6, although the percentage of vessels boarded stays relatively constant.. Addition of helicopters results in allowing cutters to board more "efficiently" by concentrating boardings on vessels of higher suspicion levels, which in turn increases the likelihood of interdicting and seizing vessels carrying contraband (assuming a positive correlation between suspicion level and illegal activity).

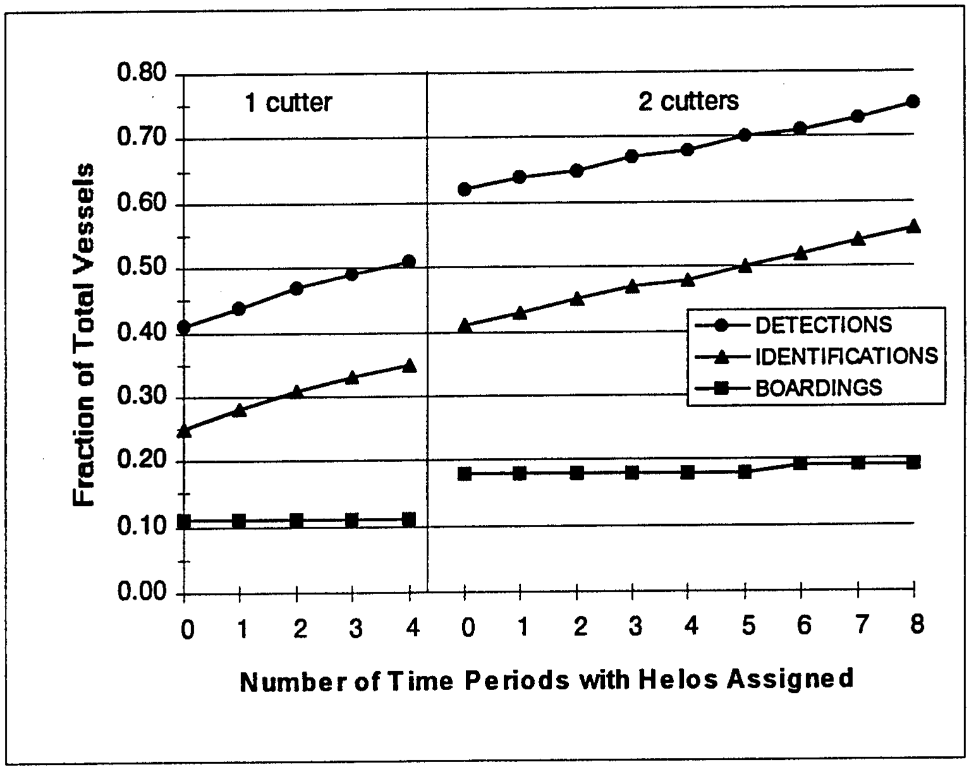

Figure 6. Percentage of Vessels Detected, Identified and Boarded

Figures 7 and 8 show that the addition of helicopters also improves the overall utilization of assigned cutters by decreasing time spent patrolling, increasing time spent boarding, and holding intercept time constant. In addition, the utilization of helicopters was found to be dependent on how "busy" the cutter was. The "busier" the cutter is, the lower the helicopter utilization, which was defined as the percentage of available flight hours actually flown.

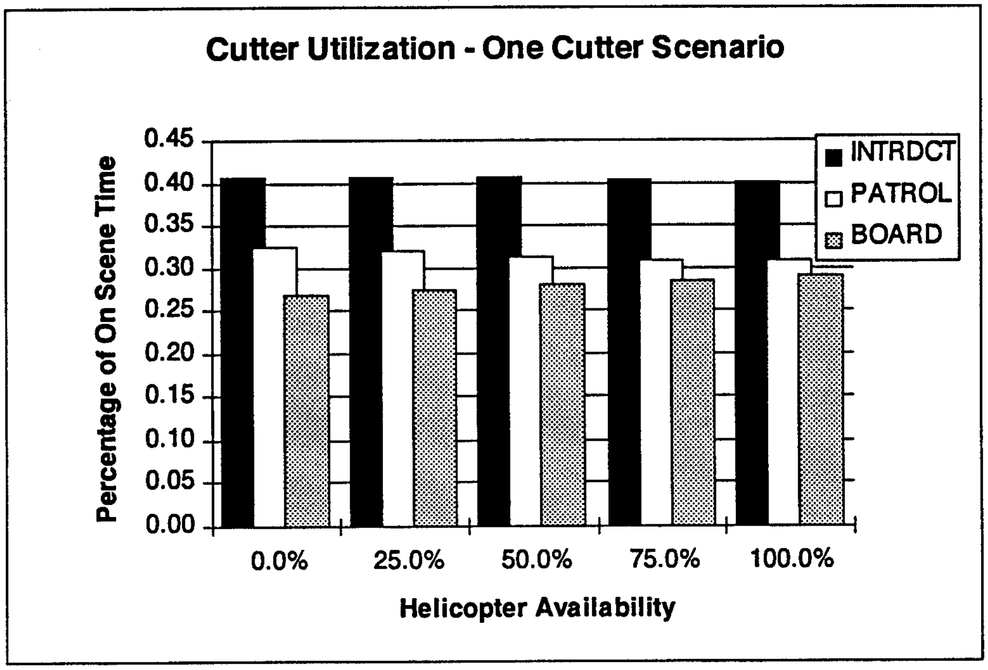

Figure 7. Single Cutter Utilization with Additional Helicopter Availability

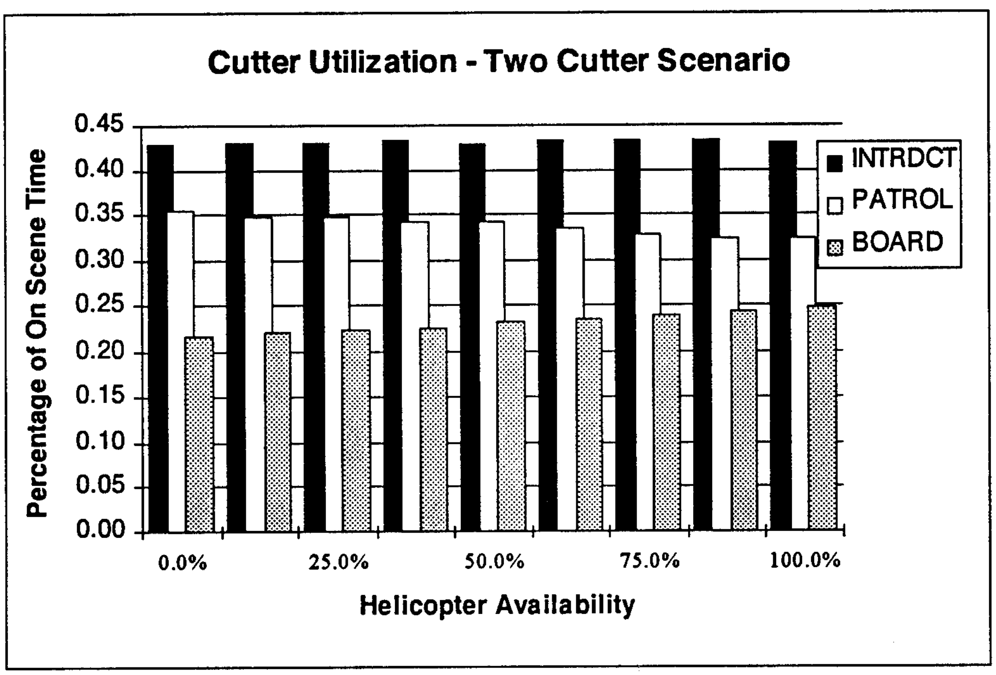

Figure 8. Dual Cutter Utilization with Additional Helicopter Availability

Threat level was identified as one of the most influential variables on the output of the simulation model. Five different threat levels (from 429 to 5556 vessels) were tested to determine the effects of threat level on performance measures. Increasing threat decreases all of the given performance measures, reduces the fraction of vessels seized, reduces cutter boarding "efficiency", and reduces helo utilization. On the other hand, cutter utilization measures are improved as threat level increases because less time is spent searching for contacts to board. Understanding the relationships between the threat level and the performance measures of interest enables realistic performance measure standards to be established. The influence of the threat level on performance should be taken into consideration when evaluating a particular resource's past performance. Seasonal fluctuations in the level of the threat would necessarily result in seasonal fluctuations in the performance a resource is capable of attaining.

The impact of considering costs in resource allocation decisions was explored. In this case, the costs and benefits of augmenting a WMEC with another WMEC were compared to those of augmenting it with a helicopter. Using activity based measures may result in one decision, cost based measures may result in a different decision, and decisions made combining both costs and activity measures may result in yet another decision. Using the activity measures indicated that augmenting a WMEC with another WMEC was preferable to merely assigning a helicopter to it. Using the cost measures alone showed addition of a helicopter was much less expensive than adding another WMEC. Combining the two measures into a cost/effectiveness measure showed adding a helicopter to be the most cost effective alternative as shown in Figures 9 and 10 below.

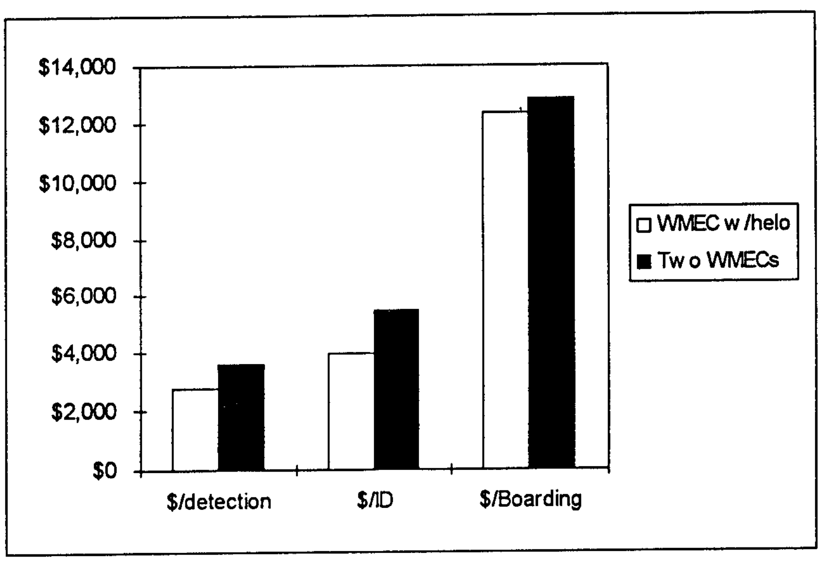

Figure 9. Cost/Performance of Additional Cutter vs Additional Helicopter

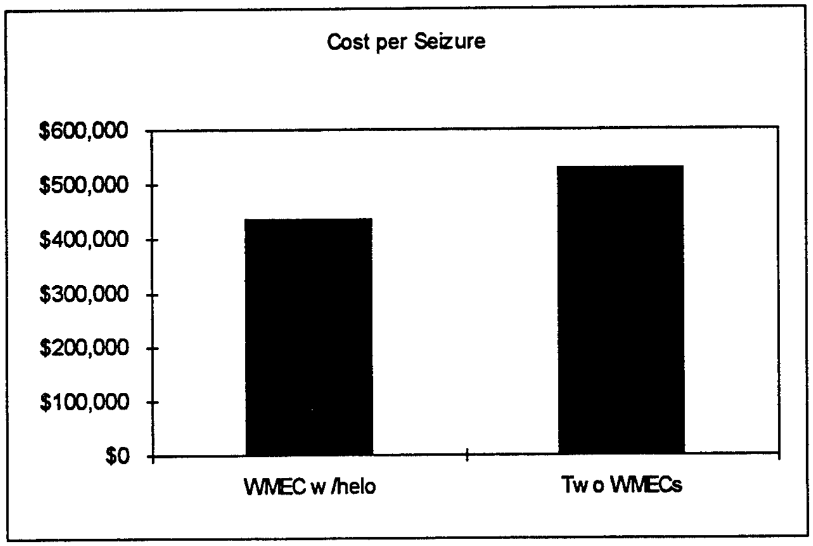

Figure 10. Cost / Seizure for Two Cutters vs Cutter-Helicopter Combination

4.3.3 Capability Enhancement

4.3.3.1 Objective

This analysis used LESIM to determine the effects of adding an AN/APS-137 radar to a cutter operating in the Windward Passage on LE mission performance. The AN/APS-137 radar is an advanced, synthetic aperture radar with several improved capabilities over conventional surface search radar. To begin with, detection range is increased to the point that, under certain environmental conditions, it provides over the horizon detection capability. Secondly, the radar echo is clear enough that a skilled operator is able to determine the type and size of a vessel based on this input alone. This enhanced capability was expected to greatly improve the mission effectiveness of high and medium endurance cutters.

Detection and classification are essential functional requirements of the law enforcement mission, but they are not sufficient in and of themselves. There are several other requirements which must also be met to achieve mission success, including identification, interception and boarding. So while improved detection and classification capability might improve overall LE mission performance, this is not guaranteed. Other methods of enhancing these capabilities exist as well, so even if this increased capability does improve LE performance, the degree of improvement and the costs of the enhancement must be compared to other feasible alternatives.

The purpose of this analysis was, therefore, to investigate first of all whether enhancing the detection and classification capability of Coast Guard cutters was beneficial to the overall LE mission, and secondly, how the costs and benefits of enhancing this capability by using the AN/APS-137 compare to the costs and benefits of using an attached helicopter.

4.3.3.2 Description of the Analysis

A single WMEC was assigned to a barrier patrol in the Windward Pass for a 180 day patrol period. Although Coast Guard cutters do not actually patrol for this length of time, changes of the patrolling cutter are not important in this study; this long patrol can be thought of as ten eighteen-day patrols. During the 180 day period, an average of 4586 vessels transited through the pass, approximately 25 vessels per day.

The performance measures used for comparison were:

- percentage of all vessels detected by radar
- percentage of all vessels visually identified
- percentage of all vessels boarded
- percentage of time a cutter spends actually boarding, interdicting, and patrolling
- percentage of contraband-carrying vessels detected and seized
- fraction of boardings which result in seizure, and
- costs.

It is reasonable to assume that there will be a marked increase in the percentage of vessels detected by radar, simply because of the enhanced detection capability. The percentages of vessels visually identified and boarded, however, depend on other characteristics of the vessel, so, while the enhanced cutter should perform at least as well in these categories as the unenhanced cutter, the degree of improvement, if any, is uncertain. The cutter utilization measures (percentage of time spent boarding, interdicting and patrolling) will be effected by the enhanced detection and classification capability, since less time should be spent closing contacts which are classified as not of interest, and consequently more contacts of interest should be interdicted and boarded.

In order to model the long-range classification capability of the APS-137, each vessel type/size combination was assigned a threat priority level from 1 to 10. This priority level, denoted TL1 (low priority) to TL10 (high priority) is a class specific attribute. For example, all large merchant vessels would have the same priority level. The priority level was used in two different ways. In every case, it was used to choose which of multiple radar contacts to pursue. In certain experiments, it was also used as a screening process; vessels below a specified priority level (TL6) were not pursued at all.

The effect of the enhanced capability on the seizure of contraband carrying vessels, and on the fraction of boardings which result in seizure, is highly dependent on the quality of intelligence provided to the cutter. In the simulation, this is modeled by the correlation between the violation indicator and the threat priority level, both of which are class attributes in the simulation. That is, the probability that a vessel is committing a seizable violation is determined by its type and size, as is the priority level (the level of LE interest in that class of vessel). The decision to intercept and board is based on the priority level, so if the intelligence estimate that one type of vessel is more likely to commit a violation is accurate, this prioritization will result in more seizures.

In analyzing the effect of a new technology, it is important that the potential benefits not be limited by current policies and practices. For this reason, the enhanced radar capability was tested using several alternative operational practices. These alternatives were:

> APS-137 used in the same manner as 'conventional' surface search radar. The performance of a cutter equipped with an AN/APS-137 radar and a cutter equipped with a radar similar to an upgraded AN/SPS-64 radar were compared, while the cutters employed the same policies and tactics.

> Intercept speed effect. The effect of intercept speed on performance was examined. The APS-137 equipped cutter was given the ability to increase speed to a maximum of 18 knots to intercept contacts of high priority. Conventionally equipped cutters, since they are unable to distinguish type and size of a contact at detection range, treated all contacts equally.

> Priority threshold effect. The effect of two distinct intercept policies was examined. The first policy is one of always pursuing the highest priority RADAR contact held. The second policy is one of pursuing only those contacts that have a priority above a user-defined minimum. This experiment consisted of comparing the performance measures of AN/APS-137 equipped cutters using each of these two policies against the same threat.

4.3.3.3 Summary of Results

To answer the question of whether the enhanced detection and classification capability improves LE mission performance, the APS-equipped cutter was compared to a cutter with a conventional radar. The results are shown in Figure 11.

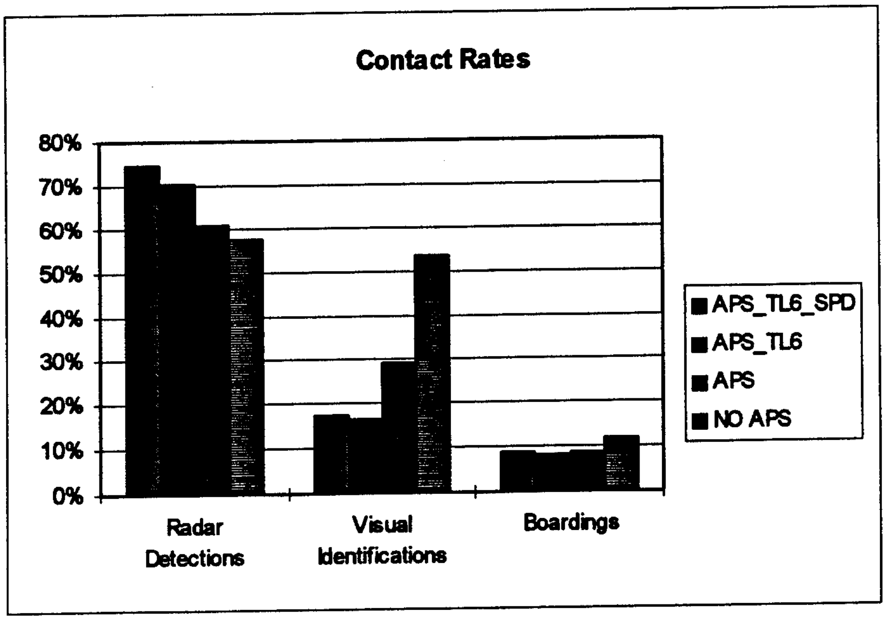

Figure 11. Percentage of All Traffic Detected, Identified and Boarded

As expected, the APS-equipped cutter increased radar detections in all cases. The percentage of traffic visually identified, however, drops significantly for the APS-equipped cutter, especially if the threat priority threshold is used. This is a result of the intentional decision not to pursue vessel contacts that are below the threat priority threshold. In other words, if a supertanker is classified at a long distance, the cutter would not close to visual identification range if the threshold criterion was being applied. The percentage of vessels boarded remains fairly constant, which demonstrates the propensity of cutters to take advantage of whatever boarding opportunities are present. Presumably, in the case of the APS equipped cutter, these opportunities are more fruitful since they are pre-screened. This presumption is tested by the remaining effectiveness measures.

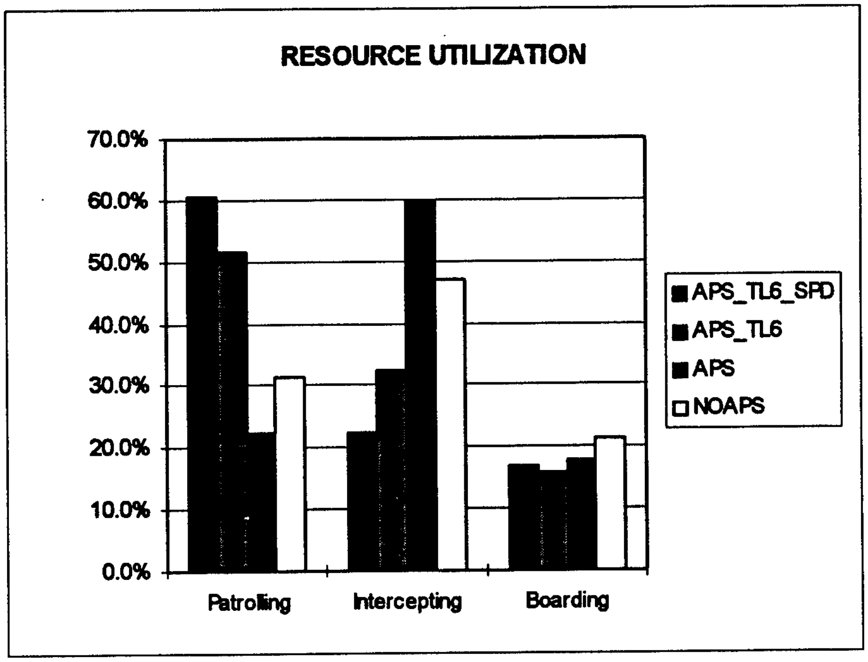

Figure 12. Resource Utilization

Figure 12 shows how patrolling cutters divided the time they spent in the patrol area. The bulk of the difference between APS-equipped cutters and conventionally outfitted cutters is in the amount of time spent patrolling (no active contacts) vs intercepting. Cutters with the capability to distinguish uninteresting targets at a distance, and the authority to choose not to pursue them, spend a proportionally greater percentage of time patrolling. Those that must pursue every contact spend more time intercepting. When it comes to those vessels that actually carried contraband, however, the ability to detect and classify contacts at long range is clearly advantageous, as shown in Figure 13.

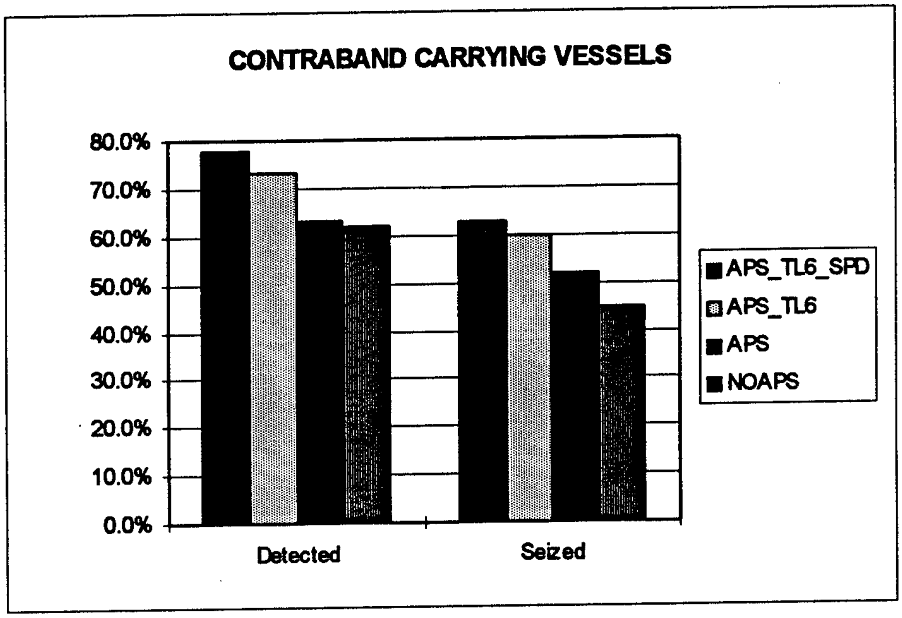

Figure 13. Contraband Carrying Vessels Detected and Seized

Once the improvement in mission performance was established, the next step was to compare the costs and benefits of equipping cutters with an APS-137 to equipping cutters with a helicopter. A helicopter, when it is airborne, provides the cutter with many of the same advantages as the APS-137, such as long range detection and classification. In addition, the helicopter provides long range identification capability. The performance of an APS-137 equipped cutter was compared to that of a cutter with a helo and a conventional radar. As can be seen in Figure 14, the percentage of detections and boardings was comparable, but the helicopter equipped cutter provided a large increase in percentage of vessels identified.

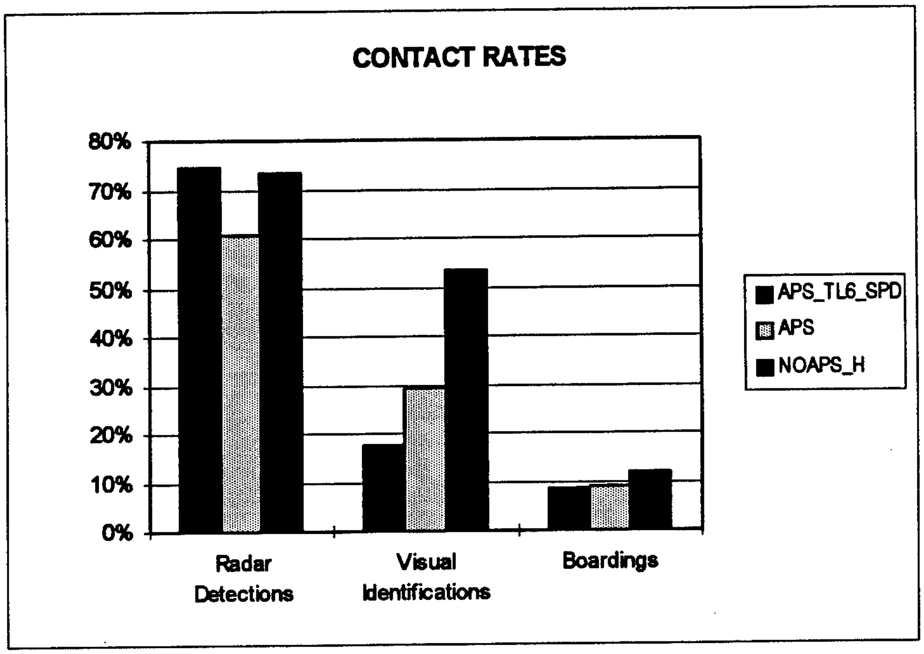

Figure 14. APS-137 vs HH-65 Detections, Identifications and Boardings

As shown in Figure 15, the performance of the two systems with respect to contraband carrying vessels was also comparable, provided that the APS-137 was used in a manner that fully exploited its capabilities. The APS equipped cutter, using the best possible tactics, seized an average of 63% of the seizable traffic during its 180 day patrol period, while the cutter without an APS seized 45%. In raw numbers, this was an increase of 9.13 seizures, or 1.5 additional seizures for every operational cutter month.

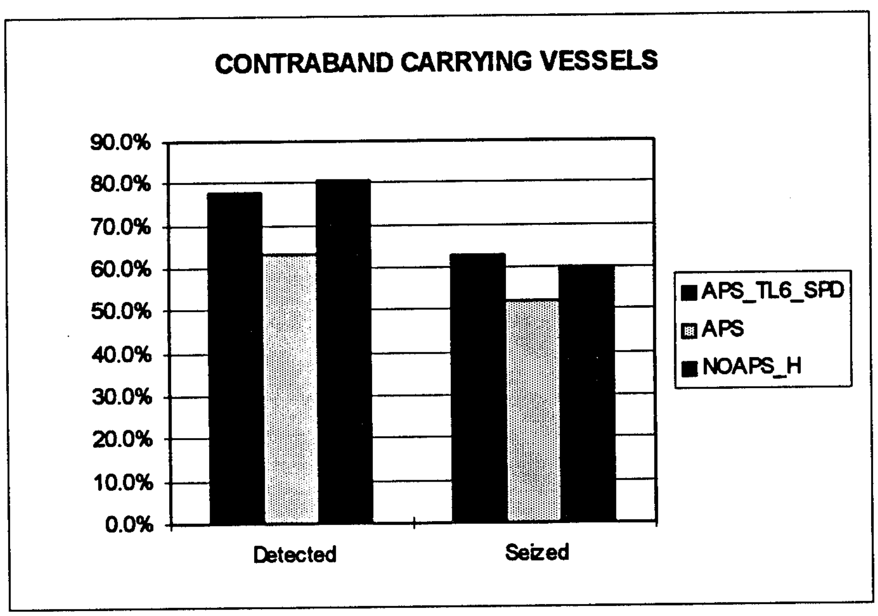

Figure 15. Comparison of APS-equipped and Helo-equipped Cutters

In order to determine if the AN/APS-137 is a cost effective investment we must look at the life cycle cost. The life cycle cost of the AN/APS-137 program has been estimated to be $214.6 million (undiscounted) for 41 systems, each with a life expectancy of 20 years[8]. During a 20 year lifetime, a 210' WMEC could be expected to perform the equivalent of eighteen 180 day patrols, with an expected increase in seizures (over the conventionally equipped cutter) of 164. This breaks down to an additional cost of $32,000 per additional seizure, which is equivalent to 22.42 hours of cutter time. Of course, some of these costs would be offset by savings in fuel expended pursuing low priority targets.

In comparison, the cutter without an AN/APS-137, but with a helo, showed an average increase of 7.66 seizures during the 180 day period, or about .85 more seizures per operational cutter month than the unenhanced cutter acting alone. The additional cost of providing a helicopter for these patrols, as determined using COMDTINST 7310.1E[9], is $1.75 million[10], resulting in a cost per additional seizure of $239,000. Clearly the APS-137 is a much more cost effective capability enhancement than the HH-65, when judged in terms of vessels seized.

The difference in cost must be weighed against the ability of the helo to rapidly, visually identify contacts and therefore determine the level of suspicion for a specific contact. Since this ability implies that a trained observer will actually see a specific target, and make a reasoned judgment based on their observation, it reduces the reliance on an accurate threat prioritization for performance improvement. The AN/APS-137 operator, on the other hand, cannot distinguish enough vessel characteristics to determine a level of suspicion based on radar signature alone. Thus, the APS-137 equipped cutter is dependent to a large degree on the threat prioritization to choose between radar contacts. Performance improvements, like those noted in this study, are dependent on the assumption that prioritization is accurate. To the extent with which intelligence is good, the Coast Guard can expect performance improvements with the improved capability of the APS-137. If the intelligence picture is incomplete or inaccurate, the APS-137 will not help to improve performance.

In order to get performance enhancements from the APS-137, cutter commanding officers must adjust operational tactics. When tactics other than a high speed intercept for high priority contacts and a priority level threshold were used, it resulted in sub-optimal performance as measured by the percentage of seizable traffic detected and seized. Employing the priority threshold alone increased the number of seizures (over the cutter without an APS scenario) by only 7.73 vessels in a 180 day patrol (compared to 9.13 in the APS_TL6_SPD[11] scenario). For the price of intercepting vessels at

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[8] Justification for Use of the AN/APS-137 as a Shipboard Mission Radar, USCG R&DC Report, November 1992, pp. 3-4 - 3-6.

[9] Standard Rates, U.S. Coast Guard Commandant Instruction 7310.1E, July 13, 1991.

[10] The HH-65s in the NOAPS_H scenarios flew an average of 482.4 hours during the 180 patrol days. The cost of 1 hour of HH-65 operations is $3,638.

[11] Cutter with APS using threshold level of 6 and maximum interdiction speed.

maximum speed, an additional 25.2 seizures per cutter could be obtained over the life of the APS-137. Similarly, the high speed intercept alone accounted for 6.83 additional seizures. Adopting a priority threshold policy as well would add some 41 more seizures per cutter during the life of the APS.

4.3.4 Boarding Intensity and Threat Level Analysis

4.3.4.1 Description of Analysis

The fourth analysis conducted used LESIM to develop statistical models of changing boarding intensity (a boarding policy based on vessel suspicion level) and threat level on the seizure rate using eight different cutter combinations (same combinations as shown in Table 4. Scenario Descriptions above). Boarding intensity is the level of selectivity that a cutter employs in deciding whether or not to board threat vessels. The higher the selectivity, the fewer boardings, but those that are done have a higher probability of resulting in a seizure. The purpose of this study was to show how statistical models constructed from LESIM output can be used to improve the inferences gained from LESIM for decision making.

In order to gain insight into how boarding intensity and threat level effect seizure rates, we varied the boarding intensity from low to high and the threat level from low to high for each of eight scenarios. The average seizure rate for each set of replications of the simulation was recorded and used to build a regression model. Since the regression is a model of another model, it is known as a metamodel[12]. The metamodel is a mathematical function approximating the output of the LESIM model by sampling from numerous combinations of the simulation input parameters. A metamodel is very useful because it enables inferences to be made from the simulation model output, over the range of the input factors, without actually running the simulation at each of the input factor settings. A metamodel allows statistical comparisons of each scenario based on seizure rate, and allows predictions of the number of seizures that will be obtained given a specified number of boardings conducted, threat level, and resource allocation. This statistically based information is just another input the operational commander can use in making informed resource allocation decisions, or in predicting the performance of chosen resources.

4.3.4.2 Summary of Results

Three metamodels were constructed. The first was a regression model that used threat level, number of boardings conducted, and number of resources employed to predict seizures. This allowed statistical comparison of the seizure rates of the eight different scenarios. It also allowed construction of prediction intervals for the number of seizures based on a given threat level. For the range of data chosen for this first model, the relationship between boardings, threat level and seizures was linear. The resulting

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[12] Law, Averill M. and Kelton, W. David., (1991). Simulation Modeling & Analysis (2nd ed). New York: McGraw-Hill, Inc., pp. 679-689.

metamodel can be viewed graphically as an individual plane in 3-space for each one of the eight scenarios. The graphical representation for the two-cutter, two-helo scenario is shown in Figure 16. For this model it can be seen that as both boarding and threat levels increase, seizures increase. The statistical comparisons of the eight scenarios showed the one-cutter scenarios to be significantly different with respect to seizures than the two-cutter scenarios, however the one-cutter scenarios cannot be distinguished from one another. The same holds true for the two-cutter scenarios.

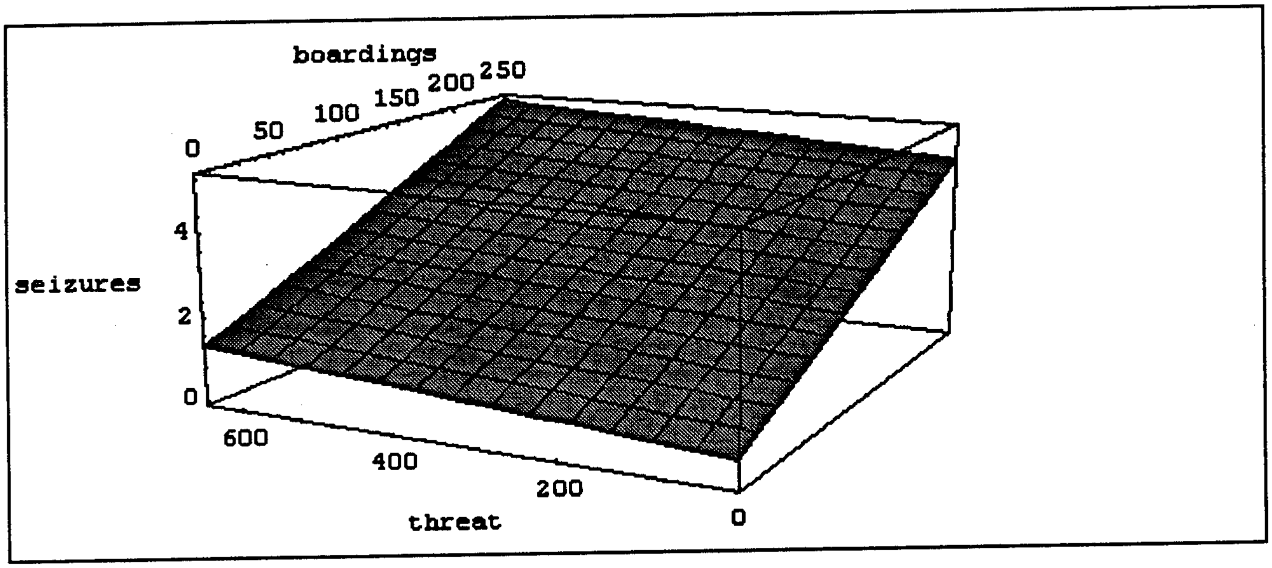

Figure 16. Seizures vs Threat Level and Boarding Level

Prediction intervals were also obtained and allow an operational commander to estimate the expected number of seizures given any threat level, boarding intensity, and resource mix. These intervals can be used to identify when changes in operational performance are out of the ordinary and should be examined more closely.

The second metamodel used the same variables as the first but investigated a greater range of input data, using only the two-cutter and two-helo scenario. This resulted in a more complex response surface. As shown in previous analyses, increasing threat level or increasing boarding intensity both increase the number of seizures made, however threat level is more influential on seizures than boarding intensity. It was discovered that the relationship between boardings, threat and seizures is not linear, instead it is quadratic, as can be seen in Figure 17.

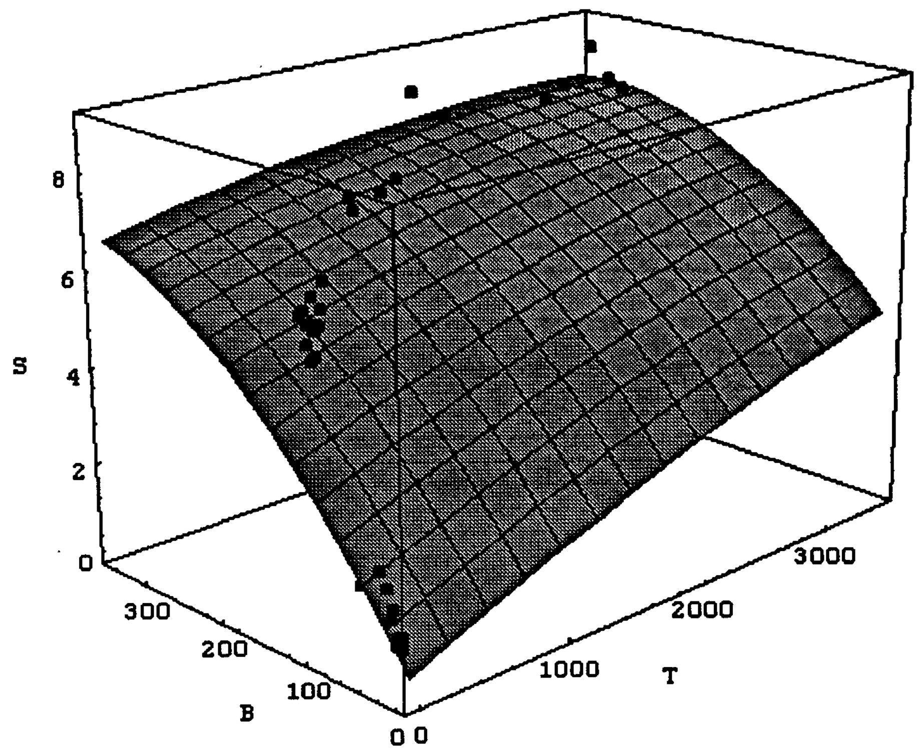

Figure 17. Relationship of Boardings and Threat Level to Seizures

When the quadratic nature of the relationship between seizures and threat was taken into account, a point where additional boardings did not result in significantly increasing seizures was determined. Given a specific threat level, using this metamodel, the optimal number of boardings to conduct can be computed to maximize the number of predicted seizures.

The third metamodel combined the one-cutter scenarios and the two-cutter scenarios to investigate the magnitude of the difference in the seizure rates between the two. Statistical tests show that all of the one-cutter scenarios were indistinguishable with respect to seizure rate, as were the two-cutter scenarios. However, employing two cutters results in a statistically significant increase in seizures over a single cutter. The results showed that with 90% confidence, the two cutter scenarios will result in between .13 and .51 more seizures that the one cutter scenarios (on average). Therefore, if maximizing seizure rates was the operational commander's goal, choosing the 210′ WMEC and the 270′ WMEC, without helicopters, would be the most cost-effective decision.

The additional inferences gained from these three metamodels highlight the usefulness of creating statistical models from LESIM output.

4.4 Code Verification

Verification is the process of determining if a simulation model is fully debugged and working as intended. The purpose of model verification is to check that the conceptual model of the system is correctly implemented in computer code[13]. The verification process for LESIM was guided by simulation experts at the Naval Postgraduate School (NPS), who outlined a set of tests to be conducted on LESIM broken into the following categories[14]:

- kinematics and fuel consumption;
- threat/SAR mission generation;
- detection;
- response to detections; and
- tactics and following schedules.

The tests used for the verification process, as specified by NPS, are listed in Appendix C. Modifications to some of the tests were necessary because of slight differences in the interpretation of the conceptual model for some components. As an example, in the test "SAR," a SAR case is to be generated, and the cutter is to go to the location of a SAR target and tracked in a manner similar to what is required in the stationary target test. This is not possible since LESIM models SAR cases only as a mission status that keeps an available resource from performing law enforcement activities. In this case, the test is modified to show that an appropriate resource is selected for the SAR case and that it is being placed in the appropriate status. Also, any tests that required sea state and visibility results were not performed since the weather model is still not considered adequate for implementation (this is a noted limitation of the model). Most of the tests were satisfactorily completed in accordance with the NPS description, and in those cases where modification was necessary, the reviewers were notified. NPS was provided with all output (generated statistics and debugging statements used to track model execution) for each of the tests conducted for independent analysis.

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[13] Law & Kelton, op. cit.

[14] Bailey & Dell, op. cit.

4.5 Conclusions

Professors Bailey and Dell of the Naval Postgraduate School provided an evaluation of LESIM, and a review of the validation and verification process conducted. Their report stated, in part:

> In recent years, the military community has developed a hierarchy of accreditation processes. This structure, described first in the Interim Policy Guidance (IPG) [1992], contained four distinct levels, where level four accreditation requires the most in-depth and rigorous testing. The methodology in the IPG was endorsed by the Secretary of Defense in DOD Directive 5000.49. We believe that, upon examination, LESIM should be granted level 3 accreditation for [comparing theater resource allocations, and evaluating equipment alternatives for USCG assets]. In brief, this means that we have examined the program and its attendant infrastructure from several aspects and found little wanting.[15]

[15] Bailey & Dell, op. cit.

5.0 RESULTS AND CONCLUSIONS

The validation process, the verification tests, and the analyses already conducted clearly show that LESIM is a viable tool to support decisions concerning law enforcement resource allocation and capability enhancement. In order to place it in operational use, end users would require a minimum amount of training (roughly one week) on scenario development and implementation, assuming that they already have the skills necessary for output data analysis.

This does not mean, however, that LESIM is a perfect tool, nor that it is the right tool for all situations. Certainly it has some limitations, and aspects that could be greatly improved. These limitations and enhancements are discussed briefly in the next sections. In spite of these shortcomings, LESIM has demonstrated that it can and should be part of the decision-making process now.

5.1 Limitations

- LESIM was developed and validated for the Seventh Coast Guard District law enforcement environment. Before applying LESIM to problems that are dependent on the geography of other areas, or that require a different concept of operations than that used in the Seventh District, the appropriate geographic plots and rule bases must be developed.
- The level of fidelity in which sensors are modeled may not be appropriate. This could be evaluated using models such as SIM II which model surface search radar in great detail.
- The traffic model does not account for marine traffic sensitive to the presence of the Coast Guard (intelligent smugglers).
- Helicopters are not modeled as distinct entities; it is currently impossible to concentrate helicopter search activity in any specific direction.
- Boarding decisions are rigid and deterministic, based only upon a vessel's suspicion level and the number of contacts queued for identification. This decision should have a probabilistic component. The only way to change the rate at which a resource boards vessels is to alter other parameters such as the boarding threshold, threat traffic level, etc. A method to increase or decrease the number of vessels boarded without altering these other factors would make analyses that incorporate these factors more robust.

In simulation modeling, certain aspects of a system may legitimately be modeled in a simplified fashion. Attention must always be given to the level of detail that system elements need to be modeled or if they should be modeled at all. Factors, such as the scope of the analysis the model is designed to support and the availability of data to validate a more complex implementation, are important considerations. The incorporation of unnecessary or unvalidated detail can reduce model validity and impose severe computational overhead.

5.2 Enhancements

In the course of using LESIM to conduct analyses as part of the validation and accreditation process, several potential improvements were noted. These are summarized in the following list:

- The weather model is applied across an entire district. This is certainly not an accurate depiction of weather in the Caribbean, but the question of whether this has any effect on the simulation results is still open. Without a doubt, the fidelity of the model could be improved by a more realistic weather model.
- The plan generator is hard to modify and maintain and does not accommodate different types of LE activities (fisheries, drug, immigration). A redesign of this component could enhance flexibility (modular, LE mission type specific rules) and facilitate maintenance.
- The pathfinder component (used to return the shortest path between two locations or two moving vessels) of the plan generator may need to be modified to reduce model run times.
- A single replication of a large scenario may take more than ten hours to run. Improvements in processing speed, both hardware and software based, would greatly increase the utility of the simulation.
- An improved user interface, incorporating the aspects of scenario development, simulation execution and output analysis, would increase usability of the simulation in a decision support role.
- A data base management system for output files should be developed so that previous simulation experiment results can be re-used, if applicable.

LESIM could be considered the framework of an advanced simulation model or decision support tool fitted to the Coast Guard's multi-mission operational environment. By using the lessons learned in the development of the LESIM prototype, in combination with the knowledge gained from the Coast Guard's experience in utilizing SIM II[16], an enhanced version of LESIM could be delivered providing a variety of analysis supporting multiple Coast Guard programs including:

- Performance analysis of programmed cutter schedules against different task-mixes and projected or historical operational tempos (increased illegal immigration and increased SAR demand).
- Performance analysis of optimized schedules, provided by external models.
- Resource-mix analysis to provide insight into the most economical allocation of resources for a given task-mix.

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[16] Naval Undersea Warfare Center, USCG Mission Effectiveness Modeling & Analysis, 28 April 1995.

- Location analysis for additional resources when available (Navy assets for example).
- Analysis of the impact of the loss of a resource or a reduction in fleet strength.
- Analysis of tactical alternatives in conjunction with capability enhancements.
- Analysis of performance improvements due to capability enhancement.
- Analysis of the cost effectiveness of alternative operational policies (implemented as a modular rule base for the plan generator).
- A library or a data base of analyses to support real-time resource allocation decisions or a variety of metamodels that provide specific decision support functions.
- Developing new measures of effectiveness for the missions that are modeled.
- Providing justification for new cutter and hardware acquisitions.
- Testing the effects on mission performance of new operational or logistical policies.
- Analysis in support of new acquisitions
- Developing new measures of effectiveness for the missions that are modeled.

A majority of the enhancements to LESIM necessary to support the above analyses are known. Most are simply the modifications required to address the current limitations noted above. Other modifications should revolve around an advanced development phase for the model that focuses on the analysis the simulation is required to support and design issues that improve performance, improve usability, and facilitate model maintenance. The computer and information system technology available today makes the development, application, and maintenance of a sophisticated model of this type highly achievable. The potential benefits from its use are immense and should be a priority.

APPENDIX A. GLOSSARY OF TERMS

Air Drop: Drug smuggling activity where aircraft are used to drop drugs to accomplices in boats.

Air Surveillance: Search and detection of marine traffic by fixed wing aircraft.

Animation Layout File: File created using Proof Animation that defines the basic graphical elements to be shown in an animation. Read Using Proof Animation by Wolverine Software Corporation for details.

Animation Trace File: File generated by a simulation to be used with Proof Animation. Read Using Proof Animation by Wolverine Software Corporation for details.

B2: Readiness status for in port cutters where the cutter must be able to get underway in 2 hours.

B6: Readiness status for cutters where the cutter must be able to get underway in 6 hours.

Board: Term used to describe a cutter engaged in a boarding.

Boarding Path: The set of way points to the point of intercept with a vessel that is to be boarded.

Boarding Threshold: The suspicion level above which a cutter will board a threat vessel.

CSAP: Cutter Scheduling Assistance Program.

Escorting: A cutter engaged in leading a seized vessel to port.

Final Intercept: See Interdict.

Geographical Filtering: Selection of a resource to respond to a SAR case based on its geographical location.

Hand-off: The transfer of custody of a threat vessel from one cutter to another for escort back to a port.

Identification: A threat vessel that has been identified by type, size, and suspicion level.

Inchop: Entry and exit location for cutters that have home ports outside the district being modeled.

Interdict: Term used to describe a cutter intercepting a vessel for a boarding.

Large: The size of a threat vessel or SAR case involving a vessel of length greater than 150 ft..

Lead Time: An estimate of the amount of advanced notification a cutter will get before an air drop occurs. Its value must always exceed the transit time threshold.

Life Threatening SAR: A search and rescue case where the potential for loss of life is significant.

Medium: The size of a threat vessel or SAR case involving a vessel with length between 35 and 150 ft..

Model: Conceptual components of the system.

Module: Code level components. Modules generally contain the code elements that implement the conceptual mode.

Non-life Threatening SAR: A search and rescue case where there is no immediate threat of the loss of life.

OPAREA: Geographic area of operation for Coast Guard and Navy vessels.

OPAREA ID: Integer value identifying an operational area.

Path Type: Numerical identifier for routes that threat vessels may utilize.

Pathfinder: The portion of the plan generator used to find optimal routes for cutters when they need to make target intercepts or paths to tactics and ports.

Paths: A set of way points that define a route from one point to another.

Patrol: Term used to describe an underway cutter not engaged with a threat vessel.

Pursue: A term used to describe a cutter in route to intercept a threat vessel for visual identification or boarding.

Radar Range: Maximum radar detection range for a cutter based upon target and sensor characteristics.

Respot Target: Call to the plan generator for readjustments to an intercept path due to course changes by the target vessel.

SAR: Search and rescue.

SES: Surface effect ship.

Small: The size of a threat vessel or SAR case involving a vessel of length 35 ft. or less.

Spotting: Short for radar spotting. The radar detection of a threat vessel.

Suspicion Level: Threat traffic is assigned a suspicion level from 1 to 5, 1 being not suspicious and 5 being highly suspicious.

Tactic: The default path a cutter follows when not pursuing or intercepting a contact.

Threat: Marine traffic other than Coast Guard and Navy vessels.

VAX/VMS: Digital equipment corporation VAX (Virtual Address eXtended) computer running under VMS (Virtual Memory System) operating system.

Violation Indicator: An attribute, implemented as a binary variable, given to threat vessels to identify those requiring seizure.

Visual ID Queue: List of threat vessels detected by radar and placed on a queue to be identified later.

WHEC: High endurance cutter.

WMEC: Medium endurance cutter.

WPB: Patrol boat.

APPENDIX B. CUTTER SCHEDULE OPTIMIZATION MODEL

Below is a listing of the GAMS model developed by Professor Dell of the Naval Postgraduate School.

```
$TITLE SEVENTH DISTRICT CUTTER SCHEDULING
$OFFUPPER OFFSYMLIST OFFSYMXREF INLINECOM { }
OPTION LIMROW = 0, LIMCOL = 0, SOLPRINT = OFF, ITERLIM = 100000000;
OPTION RESLIM = 1000;
OPTION OPTCR = 0.02, OPTCA = 1.0;
* OPTION LP = XA, MIP = XA, RMIP = XA;

$ONTEXT
FILE: CUTSIM.GMS main program for CutSIM: Cutter Scheduler for LESIM
    CutSIM is a mixed integer programming model for scheduling
    seventh and eighth United States Coast Guard District assets.
    The model outputs solutions for use in LESIM (Law Enforcement
    Simulation model) developed by the Coast Guard Research and
    Development Center, Systems Analysis Branch, Groton, CT.

    CutSIM developed by:
            Dr. Robert F. Dell
            Operations Research Department
            Naval Postgraduate School
            Monterey, California 93943-5000
            Tel. (408) 656-2853

            Original:  16 August 1993
            Update:    27 September 1993
                       24 January   1994

    for Coast Guard Research and Development Center, Systems Analysis Branch

This program requires two data files, cutter.txt and input.txt

$OFFTEXT

$INCLUDE CUTTER.TXT

PARAMETER BIGCUT(S) all cutters over 110;
BIGCUT(S) = 0;
BIGCUT(S378) = 1;
BIGCUT(S270) = 1;
BIGCUT(S213) = 1;
BIGCUT(S210) = 1;
```

```
PARAMETER GRPCUT(S) all cutters 110 feet and under;
GRPCUT(S) = 1;
GRPCUT(S378) = 0;
GRPCUT(S270) = 0;
GRPCUT(S213) = 0;
GRPCUT(S210) = 0;

SETS
  T time periods /T1 * T5/  {weeks 1 to 5}
  A patrol areas
  /
  CH  {Charleston, South Carolina}
  MP  {May Port, Florida}
  MI  {Miami, Florida}
  KW  {Key West, Florida}
  SP  {St. Pete, Florida}
  BC  {Bahamas Channel}
  WP  {Windward Pass}
  GA  {GANTSEC}
  BV  {British Virgin Islands}
  DP  {Departure Zone}
  YU  {Yucatan Pass}
  /
  H helicopter  /N,HH_65,HH_3F/ {N for none}
  HR(H)        /HH_65,HH_3F/
  D dates      /STARTD, FINISHD/
  APASS(A) 210 areas /BC, WP, GA, BV, YU, DP/
  GPASS(A) 82\110 group areas /CH, MP, MI, KW, SP/
  ADP(A) 270\378 areas /DP/
  L level of undersatisfaction /1*20/
   {used in calculating penalty for not supplying number of assets requested}
  ;

ALIAS (L,LL)
$INCLUDE INPUT.TXT
```

```
PARAMETER OK(S,A,T) 1 if ship s can patrol area a in time t;
OK(S,A,T) = 0;                {initialize}
OK(S,APASS,T)$(AVAIL(S,T)) = 1$BIGCUT(S);
                       {only large cutters away from group areas}
OK(SCH,"CH",T)$(AVAIL(SCH,T)) = 1;  {group asset only}
OK(SMP,"MP",T)$(AVAIL(SMP,T)) = 1;  {group asset only}
OK(SMI,"MI",T)$(AVAIL(SMI,T)) = 1;  {group asset only}
OK(SKW,"KW",T)$(AVAIL(SKW,T)) = 1;  {group asset only}
OK(SSP,"SP",T)$(AVAIL(SSP,T)) = 1;  {group asset only}
OK(S,ADP,T) = 0;              {only 270 and 378 in DP}
OK(S270,ADP,T)$(AVAIL(S270,T)) = 1;
OK(S378,A,T) = 0;
OK(S378,ADP,T)$(AVAIL(S378,T)) = 1; {378 only in DP}

PARAMETER OKH(S,A,T,H) 1 if can use helicopter;
OKH(S,A,T,"N") = OK(S,A,T)$BIGCUT(S);
OKH(S,A,T,HR)$OKHELO(S,HR) = OK(S,A,T)$BIGCUT(S);

PARAMETER OKSA(S,A) 1 if ship s can ever patrol area a;
OKSA(S,A)$(SUM(T, OK(S,A,T)) GT 0) = 1;

PARAMETER C_PEN(A,T,L) penalty for having L patrols less than desired;
C_PEN(A,T,L) = 0;
C_PEN(A,T,L)$(ORD(L) LE C_GOAL(A))
      = SUM(LL$(ORD(LL) EQ (C_GOAL(A) - ORD(L) + 1)),
        C_DESIRE(A,LL));

PARAMETER H_DESIRE(A,H,L) desire of having L helicopters patrolling;
H_DESIRE(A,"HH_65",L) = HH65_WANT(A,L);
H_DESIRE(A,"HH_3F",L) = HH3F_WANT(A,L);

PARAMETER H_PEN(A,T,H,L) penalty for having L patrols less than desired;
H_PEN(A,T,H,L) = 0;
H_PEN(APASS,T,H,L)$(ORD(L) LE H_GOAL(APASS,H))
      = SUM(LL$(ORD(LL) EQ (H_GOAL(APASS,H) - ORD(L) + 1)),
        H_DESIRE(APASS,H,LL));

PARAMETER COK(A,T,L) 1 if area can have L less patrols than desired ;
COK(A,T,L) = 1;
COK(A,T,L)$(ORD(L) GT C_GOAL(A)) = 0;
COK(GPASS,T,L)$(ORD(L) GT C_GOAL(GPASS)) = 0;
COK(A,T,L)$(C_GOAL(A) EQ 0) = 0;

PARAMETER HOK(A,T,H,L) 1 if area can have L less helos than desired ;
HOK(A,T,H,L) = 1;
HOK(A,T,H,L)$(ORD(L) GT H_GOAL(A,H)) = 0;
HOK(GPASS,T,H,L) = 0;
HOK(A,T,H,L)$(H_GOAL(A,H) EQ 0) = 0;
```

```
VARIABLES

  G_CUTTER(S,A,T)  cutter s assigned area a at time t
  A_CUTTER(S,A,H)  cutter s assigned to area a (area assets only)
  C_DEV(A,T,L)    L less patrols in week T area A than desired
  H_DEV(A,T,H,L)  L less helos in week T area A than desired
  MISSED          objective function value
 ;

POSITIVE VARIABLE C_DEV , H_DEV;
BINARY VARIABLE G_CUTTER, A_CUTTER;

C_DEV.UP(A,T,L) = 1;
H_DEV.UP(A,T,H,L) = 1;

EQUATIONS

  COVER          define the objective function
  SHIPCOVER(A,T)   elastic constraint measures cutters in A during T
  HELOCOVER(A,T,H) elastic constraint measures helos in A during T
  HELOMAX(T,H)     limit number of helos available during T
  ONEJOB(S)       one job only for area cutters
  WEEKLY(S,T)     group cutters can not have consecutive patrols;

COVER .. MISSED =E= SUM((A,T,L), C_PEN(A,T,L) *
          C_DEV(A,T,L)$COK(A,T,L)) + SUM((A,T,H,L), H_PEN(A,T,H,L) *
          H_DEV(A,T,H,L)$HOK(A,T,H,L));

SHIPCOVER(A,T) .. SUM((S,H)$BIGCUT(S),
          A_CUTTER(S,A,H)$(OKH(S,A,T,H))) + SUM(S$GRPCUT(S),
          G_CUTTER(S,A,T)$(OK(S,A,T))) =G= C_GOAL(A) -
          SUM(L,C_DEV(A,T,L)$COK(A,T,L));

HELOCOVER(APASS,T,HR) .. SUM(S$BIGCUT(S),
          A_CUTTER(S,APASS,HR)$(OKH(S,APASS,T,HR))) =G=
          GOAL(APASS,HR) -
          SUM(L,H_DEV(APASS,T,HR,L)$HOK(APASS,T,HR,L));

HELOMAX(T,HR) .. SUM((S,APASS)$BIGCUT(S),
          A_CUTTER(S,APASS,HR)$(OKH(S,APASS,T,HR))) =L= MAXHELO(HR);

ONEJOB(S)$BIGCUT(S) .. SUM((APASS,H),
          A_CUTTER(S,APASS,H)$(OKSA(S,APASS))) =L= 1;

WEEKLY(S,T)$(GRPCUT(S) AND (ORD(T) GT 1)) ..
  SUM(GPASS, G_CUTTER(S,GPASS,T-1)$(OK(S,GPASS,T-1)))
 + SUM(GPASS, G_CUTTER(S,GPASS,T)  $(OK(S,GPASS,T)))
                =L= 1;

MODEL SCHEDULE /ALL/;

SOLVE SCHEDULE USING MIP MINIMIZING MISSED;
```

APPENDIX C. MODEL VERIFICATION TESTS

The following verification tests were requested by Professor Michael Bailey, Naval Postgraduate School:

- Simple Transit: Start a single, fully fueled cutter from a port. Send the cutter at a constant speed to a tactic which is not obscured by land, so that the cutter travels in a straight line to the tactic. Make the tactic very small, so it is as if there is just a destination point P. Output sought:

  · the time of arrival at P; and

  · the fuel remaining at the time of arrival.

- 30% Fuel: Run the cutter in the tactic around P until it reaches 30% fuel. Output all ensuing events. (All tactics currently employed in LESIM should be tested using just one cutter type.)
- Stationary Target: To the simple transit test, add a stationary, radar-reflecting target craft located at P. Establish the radar range of the cutter as R, and set visibility to near 0.0. Output sought:

  · the time of first detection;

  · the input to and result of any classification algorithm; and

  · the trace of any ensuing events.

- Stationary Cutter: Perform the stationary target test, except cause the cutter to be as close to stationary as possible, and send a threat straight at the cutter. Same output as stationary target.
- SAR: Repeat the stationary target test, except the target is a SAR target. Produce the same output.
- Land Avoidance: Perform the simple transit test, except cause the cutter to avoid a land mass.
- Moving Target: Identical to the stationary target, except that the target is now moving. If the cutter transit is due east, 090, the target should be presented moving on courses 000, 090, 135, 250 at speeds v/2 and 2v. Arrange timing so that there should be an observed detection. Same output.
- Moving Threats: Same as the moving target, except that there should be 2, 3 and 6 threats in the immediate vicinity of P when the cutter comes on station. All threats should be moving in different directions. Same output as moving target.
- Multiple Cutters: Repeat the Stationary Cutter test using two cutters at two different locations. Justify the simulation's choice of responding cutter to a single SAR mission (repeat for a single threat). Justify choice of cutter for cases where closest cutter is busy boarding a highly suspicious contact, interdicting a highly

suspicious contact, attending a life threatening SAR case, of attending a non-life threatening SAR case.

- Air Drop: Cause an air drop to one of the vessels in the multiple threat test. Produce the same output as moving target.
- Sea States: Same as moving target, except that the sea state should be varied in 2, 3, and 4. Output should include all of those items shown for both simple transit and moving target.
- Visual: Set the radar range to near 0 and establish visual ranges from 3, 10, 30. Try each visual range in the moving target test with sea states 2, 3, and 4.
- Threat Parade: Set up a tactic of very small size, and parade suspects through the tactic at rate l. Put one, two, and five cutters in the tactic. Show a trace of all response events in [0,10/l].
- SAR Conflict: Cause the cutter to receive a life-threatening SAR mission at time 0 in the threat parade test. Output all ensuing response events.
- SAR Conflict 2: Cause a life-threatening SAR to occur while the cutter is prosecuting a suspect. Output all ensuing response events.
- Schedules: Specify as data a cutter's OPAREA and helicopter accompaniment. Ensure cutter receives preferred tactic in OPAREA. Assign two cutters to OPAREA and ensure each cutter receives appropriate tactic.