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PATROL PLAN OF MOTOR GUNBOAT (PGM. ALLIED CLASS) FOR INFILTRATION FROM SEA

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THESIS

PATROL PLAN OF MOTOR GUNBOAT
(PGM. ALLIED CLASS) FOR INFILTRATION
FROM SEA

by

Chavalit Israngkul
Matra Ampaipast

September 1974

Thesis Advisor: R. N. Forrest

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Block #20 continued

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Patrol Plan of Motor Gunboat (PGM. Allied Class)
For Infiltration From Sea

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ABSTRACT

Patrol plans have been developed for use by Motor Gunboats to counter small scale infiltration by insurgents from the sea. The objective in developing the patrol plans was to determine the optimum deployment of the generally limited number of patrol craft available to developing nations. The patrol plan to be used is determined by a probability distribution associated with incoming targets.

TABLE OF CONTENTS

I. INTRODUCTION

Emerging and developing nations today generally face a host of problems. In addition to internal political conflict, these nations are now threatened by internal subversion encouraged and assisted by outside nations. The movement of insurgents has often been closely tied to the sea because men, arms and supplies can land clandestinely over beaches. To reduce internal subversion, the developing nation needs the means to prevent the shipment of men and arms by sea where such shipment is possible.

The purpose of this paper is to develop patrol plans for PGM's, allied class, to be used in patrolling the coastal waters of the nation which possesses these craft in order to prevent entry or departure by sea of insurgents.

The paper is arranged in five sections. The first section looks at the infiltration by sea from the point of view of the internal subversion within developing countries which is encouraged and assisted by outside nations. The second section deals with the characteristic of the motor gunboat (PGM). The third section discusses the concept of patrol operations, the definition of an operational area and the units to be employed to support a partol operation. The forth section discusses the design considerations in the patrol plan for PGM. In particular, it dwells on methods of computing the allocation of patrol effort to the assigned

areas of a barrier patrol. The final section provides the important conclusions from the materials in this paper.

II. INFILTRATION FROM THE SEA

The world situation is characterized by rapid social, economic, and political changes. These conditions have created some problems in the maintenance of internal security for many developing nations in Africa, Southeast Asia, and Latin America. The situation is further compounded by the fact that Communist countries are attempting to promote subversion and insurgency in many of the developing nations in these areas. The problems of internal defense are difficult for any nation to solve. The coastlines of some countries in Africa, Asia, and Latin America are extensive and in many instances, their frontiers run through areas of rugged terrain making them difficult to patrol.

A. INSURGENCY SUPPLY ROUTES

When a country has internal conflict, the primary targets of subversion and insurgency are the internal security forces of the nation; that is, the civilian police forces, the paramilitary forces, and the military forces. The insurgents need arms, are well educated, and have trained men to achieve their purposes. In order to have well educated and trained men, the insurgents need schools to train cadre in the tactics, techniques, and strategy of insurgent operations and methods; most frequently these schools are

located in a foreign nation, outside of the area of conflict.[1] After training, these men can be expected to try to infiltrate back to the area of conflict by the easiest route. Arms are also collected and supplied from the foreign nation. The most economical and direct routes for supply when they are available are sea routes. When insurgents can resupply men and arms by sea they will likely do so.

B. INSURGENCIES SUPPLIED BY SEA IN THE PAST

Since World War II an unprecedented number of insurgencies have occurred throughout the world, may have been instigated or aided by other nations. The following six listed insurgencies involved resupply by sea.[2]

Malaya (1948-1960): The long and irregular coastline of Malaya posed an entrance problem. Many small craft plied those coastal waters. The British Navy assumed operational control of all offshore as well as inshore patrols and was assisted by police launches. The primary objective was to intercept possible Communist reinforcements by sea and to prevent the smuggling of arms and ammunition into the country. The British Government and the Royal Navy maintained that these patrols deterred the Communists from

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[1]Jerry M. Tinker, Andrew R. Molnar, and John O. Lenoir, Strategies of Revolutionary Warfare, p. 145, New Delhi S. Chand & Co., 1969.

[2]Adrain H. Jones, *et al*, Internal Defense Against Insurgency: Six Cases, Washington, D. C., Center for Research in Social System, The American University, 1966.

dispatching reinforcements from China by sea. Infrequently, however, small groups of Communists did land at remote coves and inlets.

The Philippines (1946-1954): Although there are 14,000 miles of coastline in the Philippines, preventing the supply by sea of the Huk insurgents with arms and equipment from outside the country never became a problem for the internal security forces to combat. This fact worked to the advantage of the Government, since the Huks had only a limited number of small arms.

Cuba (1953-1959): One of the most difficult problems faced by the Government internal security forces was that of the interception of shipments of arms, munitions, equipment and other supplies destined for the insurgents. Supplies received from outside the area were intercepted by the Government. In addition to receiving supplies by boat, the insurgents also cleared landing strips to receive supplies shipped by air from foreign countries.

Venezuela (1960-1965): Cuba was being used as a sanctuary where insurgents were trained and where shipments of supplies and arms originated. One of the difficult problems which confronted the Government was the prevention of the infiltration of men, arms, and munitions into the country.

Algeria (1954-1962): The lengthy coastline and common boarders with Tunisia and Morocco posed a problem for the French. Numerous small crafts engaged in supplying arms,

munitions, and supplies to the insurgents. On October 16, 1956, French Naval units stopped and boarded the ship Atos off the Cap de Trois-Fourches, a point near the Moroccan-Algerian border. The cargo, a consignment of 70 tons of arms, was confiscated.

South Vietnam (1954-1965): One of the difficult problems in the counter-insurgency effort was the control of the entry of personnel and supplies into South Vietnam both by land and sea. Vital supplies reaching the Viet-cong by sea included medicines, maps, and propaganda equipment in addition to arms and ammunition.

In summary, in the Philippines and Malaya, coastal access was effectively controlled. In these two insurgencies the government forces were victorious. In Algeria and Cuba the aid received by the insurgents by coastal and other external access was substantial; in both instances the insurgents were victorious. In South Vietnam insurgent aid was received from outside the country through coastal and external access. This insurgency was still in progress as of June 1974.

C. INFILTRATION TACTICS

Insurgency movements have often been closely tied to the sea and inland waterways. They have depended on the sea as a supply route and liaison channel, and on the swamps and rivers to assure an unobtrusive, sure method of transport and internal communication. Arms and supplies landed

clandestinely over beaches or in hidden inlets supplied insurgency in the Spain of 1808 as well as today's Vietnam. The insurgent's supplies, orders and equipments can come in swift patrol boats or innocent looking piroques. Unless defending forces are intimately familiar with the nature of normal maritime traffic, the waters which this traffic occurs in, offers, in effect, a safe haven for infiltrator surface craft which can "hide in the crowd" of vessels engaged in legitimate business. Control of the waterways has always been an important objective for both insurgency and counter-insurgency.

III. MOTOR GUNBOATS

Current usage of the word "boat" covers much more than the dictionary definition of "a small open vessel, or watercraft, usually moved by oars or paddles" and is not limited to its old nautical usage to cover craft which might be carried in a ship. There seems to be no precise definition of what a boat is, or is not. Consideration also has been limited to those crafts most likely to be used in combat operations, or in active patrol duties. The largest patrol crafts built under the U. S. Military Aid Program are the PGM's-Motor Gunboats. The term motor gunboat is now applied primarily to these 117 ton vessels built for allied navies.[3]

A. DISTRIBUTION LIST[4]

The first groups of this class, PGM 1-32 were submarine chasers modified during World War II for U. S. Navy PGM-33 through 38 were wooden-hulled, 143-ton gunboat versions of the 110-foot subchaser of World War II, completed from 1954 through 1956 for the Philippines. The next group, PGM 39 through 58 welded-steel crafts are lengthened versions of the U. S. Coast Guard 95-foot Cape-Class low endurance cutters. With ease of maintenance in remote corners of the

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[3]Raymond V. Buckman, Jane's Fighting Ships 1969-1970, p. 476, London, Netherwood, Dalton, 1969.

[4]Arthur Davidson Baker, III, "Small Combatants-1973; II The Oceanic Powers," United States Naval Institute Proceeding, V. 99, p. 240-269, May 1973.

world particularly in mind, all their machinery and electronic equipments were selected from commercial sources with worldwide distribution. Their power and armament were less than the original U. S. Coast Guard design. PGM 39 through 42, went to the Philippines, and PGM 43 through 46, plus 51 and 52 went to Burma. The Philippine boats had two Mercedes-Benz diesels, while the crafts for Burma had four Detroit Diesel engines. The PGM 39 class were originally armed with ASW ordnance, including depth charges and Mousetraps; they are now equipped purely as gunboats, the Philippine boats with two 20 mm AA and the Burmese with two 40 mm guns. PGM 47 through 50 were the U. S. Offshore Procurement boats of the Danish Daphne class and little U. S. equipment or design influence was employed in their construction. Ethiopia got the next three, PGM 53, 54 and 58, all of the PGM 39 class and completed in 1961-1962; like the others they initially carried ASW ordnance but now are armed as gunboats.

Beginning with PGM 55 through 57 for Indonesia, the "MAP-gunboat" underwent a design change. The craft was lengthened to 101 feet in order to accommodate more men, more fuel, and more ordnance. The Indonesian crafts were in a sense intermediate craft, as they carried only two twin 50 caliber machine guns on completion in 1961. All later U. S. built boats have carried a 40 mm/60 caliber Mk 3 gun forward, four 20 mm in a pair of twin mounts after and two single 50 caliber machine guns beside the bridge (the boats for Turkey and Iran also carried depth charges

and Mouse-trap and are distinguished by having their 40 mm mount after).

The trio of craft for Indonesia and PGM 59 through 70 for South Vietnam were engined with two Mercedes-Benz MB-820 diesels of 975 b.h.p. each. All subsequent PGM 59 class boats have been powered by the rather unlikely sounding combination of no less than eight General Motors 6V-71 diesels, geared four per shaft. Two additional diesels in the single engine room drive the two generator plants. The ships have a top speed of only about 18 knots. Range at 10 knots is over 1,500 nautical miles.

Further boats of the PGM 59 class have included PGM 71 79, 107, 113 through 117, and 123-124 for Thailand; PGM 72 through 74, 80 through 83, and 91 for South Vietnam; PGM 75 and 76 for Ecuador; PGM 77 for the Dominican Republic; PGM 78 for Peru (with PGM-111, a duplicate, built in Peru with U. S. aid during 1970-1091); PGM 102 for Liberia; PGM 102, 103, 112 and 122 for Iran; and PGM 104 through 106 and 108 for Turkey. PGM 109 and 100 and 118 through 121 are PGM 39 class craft completed during 1971 in Brazil; they are armed with an over and under 50 caliber machine gun/81 mm motor forward and two single machine guns after.

B. SUMMARY OF GUNBOAT CHARACTERISTICS[5]

Type: PGM-Motor Gunboat

Class: PGM-39/U.S. Coast Guard 95-feet

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[5] Raymond, V. B. Buckman, Jane's Fighting Ships 1971-1972, p. 516, London: Netherwood Dalton, 1971.

Displacement:	110 tons full load
Length	95 feet
Beam:	19 feet
Propulsion:	two or four diesels (distribution list) equal 2,200 b.h.p.
Speed/Range:	20 knots max.; 10 knots = 1,500 nautical miles
Armament:	distribution list
Radar:	max. effective range approx. 12 nautical miles

Countries Operating or Acquiring:

United States:	26 (retained in U.S.C.G.)
Philippines:	4
Burma:	6
Ethiopia:	5 (2 ex-U.S.C.G.)
Brazil:	6
South Korea:	9 (ex-U.S.C.G.)
Haiti:	2 (ex-U.S.C.G.)

Type:	PGM-Motor Gunboat
Class:	PGM-59
Displacement:	130 tons full load
Length:	101 feet
Beam:	22 feet
Propulsion:	two Mercedes Benz MB820 diesels = 1,900 b.h.p., or eight G.M. GV-71 diesels = 2,000 b.h.p.
Speed/Range:	18 knots max.; 10 knots = 1,500 nautical miles
Armament:	normally one 40 mm AA; two twin 20 mm AA; two single .50 cal. MG (depth charges on some

Radar:	max. effective range approx. 12 nautical miles	

Countries operating or acquiring:

Indonesia:	3
South Vietnam:	20
Thailand:	10
Eduador:	2
Dominican Republic:	1
Peru:	2
Liberia:	1
Iran:	3
Turkey:	4

C. TASKS AND MISSIONS

The boats which will perform patrol duties should be about 100 feet long, displace about 100 tons, have relatively high endurance, be seaworthy, and have all-weather operating capability. These characteristics were advocated by Secretary of Defense, Robert S. McNamara.[6]

These statements are based on unclassified sources, which did not mention the design consideration of the PGMs. But the 165-foot PG84 class, the patrol gunboat (PG, formerly PGM), is the largest patrol-type craft built by the U.S. Navy since World War II. They were designed to provide patrol, blockade, surveillance in coastal waters, perimeter defense for amphibious landings, and support for unconventional

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[6]Raymond V. Buckman, *op. cit.*, 1969, p. 476.

and guerrilla warfare.[7] The PGM cannot perform all of the PG tasks because she is smaller and has less capabilities than the PG84 class. The PGMs can, however, perform most tasks as well as PG84 class when her area of responsibility is limited to such things as support for unconventional and guerrilla warfare. Commander Andrew G. Nelson, U. S. Navy[8] stated that "PGMs in our present new construction program are bound to prove better ships and would be invaluable in performing seaward anti-infiltration patrol."[9] So a potential task and mission of these PGMs is to patrol the coastal line in order to halt infiltration of men and arms by sea. This is not inconsistent with the mission of small navies which is primarily to control coastal waters and to guard against smuggling and illegal entry or departure by sea.

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[7]Richard T. Miller, "Fight Boats of the United States," United States Naval Institute Proceeding, p. 301, Naval Review, 1968.

[8]He was assigned to the Naval Advisory Group in Vietnam from January 1964 to July 1965.

[9]Andrew G. Nelson and Norman G. Mosher, "Proposed: A Counterinsurgency Task Force," United States Naval Institute Proceeding, V. 92, p. 41, June 1966.

IV. OPERATIONAL CONCEPTS

When a sea route exists, supplies, orders and equipments for insurgents can come in by boats which normally operate in the area. So the problem of coastal defense exists for those developing nations in Asia, Africa and Latin America which have received PGMs under the United States Military Aid Program. The consideration in Section III concluded that those craft are suitable for patrol duties. This section will develop the concepts which concern the patrol plan for the PGMs.

A. OPERATIONAL OBJECTIVE

The objective of a counter-insurgency patrol is to maximize the probability of intercepting infiltrators from the sea. This means that the patrol should be conducted in the area in which the probability of intercepting an incoming target is a maximum. A developing nation with a limited number of patrol craft cannot conduct large scale patrol operations to prevent insurgency infiltration from the sea such as the Market Time Operation in Vietnam, 1965-1972,[10] or the operation of the Royal Navy in the Indonesia Confrontation 1962-1968. Both operations used different kinds

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[10] The primary mission of Market Time was "to conduct surveillance, gunfire support, visit and search, and other operations as directed along the coast of the Republic of Vietnam in detection and prevention of Communist infiltration from the sea."

of ships and aircraft in significant numbers. The Market Time Operation consisted of seven Destroyer Escorts, Two Minesweeper Oceans, two Landing Ships Tank, five Sea Patrol, 26 Patrol Gunmotors and 54 Fast Patrol Crafts. The Royal Navy Operations in the Strait of Malacca consisted of as many as fifty ships and small crafts of the Far East Fleet and companied by the Malasian Navy and Singapore Police Marine.

The main goal in the design of a barrier patrol is that the PGMs patrol in an area of maximum probability for the incoming target. This area is assumed to be determined by intelligence or by aerial search in the general infiltration area.

B. OPERATIONAL AREA

The operational or patrol area to be discussed extends seaward from the coastline about 132 nautical miles and is bounded by a line about 135 miles long which parallels the shore line. The location size of an actual area will depend on intelligence or aerial surveillance information. An operation area is shown in Figure 1. From the shore line to 12 nautical miles to seaward are the Visiting and Boarding area and the PGMs barrier patrol area, Aerial Search will be assumed to provide the information on which the probability distribution of incoming target is based. The Aerial Search area extends from 12 nautical miles to 132 nautical miles. For those navies which do not have

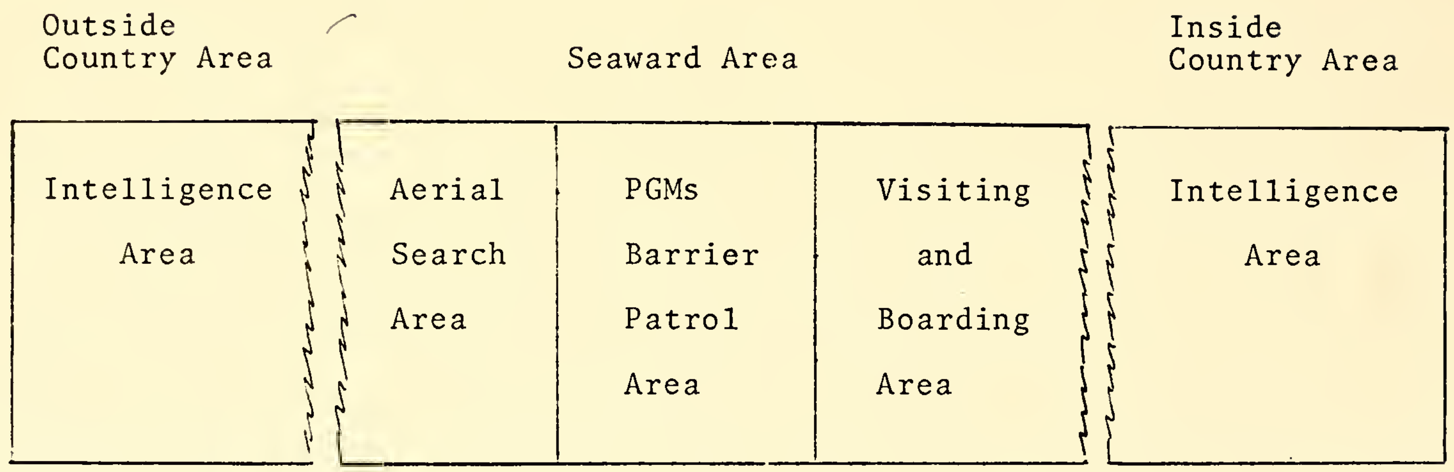


Figure 1. Operational Area.

aerial patrol, the probability distribution of the barrier crossing point of an incoming target should be provided by intelligence agencies. The visiting and boarding operations are not discussed in this paper. They will depend on the internal laws of a nation and are a topic worth further study. The surface patrol operation is the main topic of this thesis and it will be discussed in detail in the next section.

C. OPERATIONAL UNIT

The operational patrol unit employed in this paper consists of three PGMs to perform barrier patrol in the operational area. This is the unit which is the subject of the patrol plans developed in the next section. The plans can be easily modified to describe a one or two PGM patrol unit.

V. PATROL MODEL

A. ESTIMATION OF THE *A PRIORI* PROBABILITY DISTRIBUTION OF TARGETS

Patrol tactics will be established in this section. It is assumed that a patrol will be conducted when information indicates that there will be small craft carrying men and armaments approaching some area along the patrolled coast. This information must come from aerial search or intelligence sources. If the information cannot be used to estimate the *a priori* probabilities, P_A, P_B and P_C that the incoming target will cross one of the equal length patrol barrier segments A, B or C, respectively, then they might be estimated by using historical data. However, the best way to locate targets and estimate P_A, P_B and P_C presumably would be to use an aircraft to search in the area of incoming targets with a regular search [Ref. 24] as shown in Figure A-1.

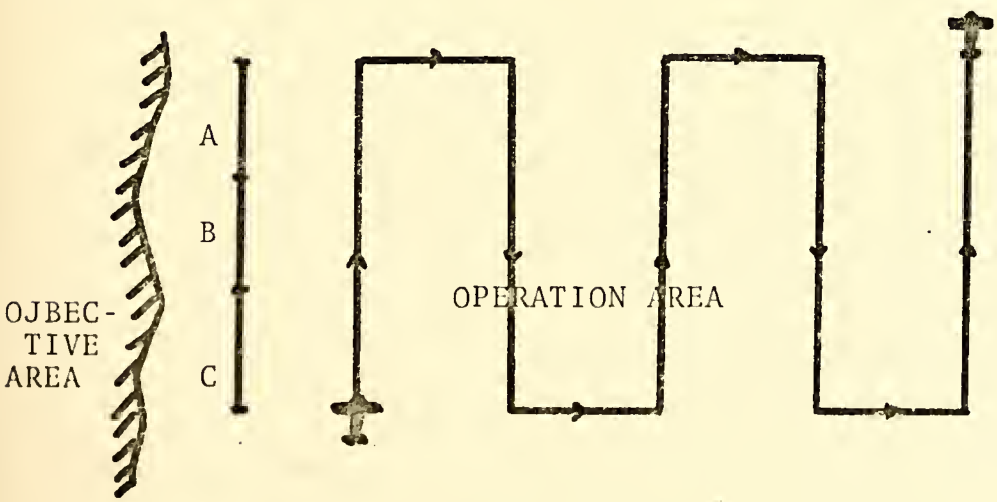


Figure A-1.

The following assumptions are made in this section: The targets are small craft and fishing boats which have the capability of long range cruising, but whose only navigational aid is a magnetic compass, so evasive maneuvers such as zig-zagging cannot be performed. Electronics countermeasure will not be used, so a target will not know when ships or aircraft patrols were in its area. A target will attempt to reach shore before dark in order to locate a landing area and the landing will occur at night. The target will not change course until it it close enough to the shore to identify the landing site, and therefore, the target will not change course before passing the barrier patrol line.

Based on the above assumptions, an aircraft should conduct a regular search in the morning, searching from the barrier line until the track is 120 miles from the barrier line in order to ensure that all those targets which would reach the barrier line before dark would be detected by the aircraft.

When a target is detected by the search aircraft's radar, it will be verified visually. To find P_A, P_B and P_C, the course of each detected target will be plotted and then a line drawn from the target's position in the direction of the course to the point where it crosses the barrier line. If a target is observed to be a boat that is fishing, or if its course line does not cross the barrier line; it will be classified as a 'false alarm', otherwise, it will be classified as a 'potential insurgent'.

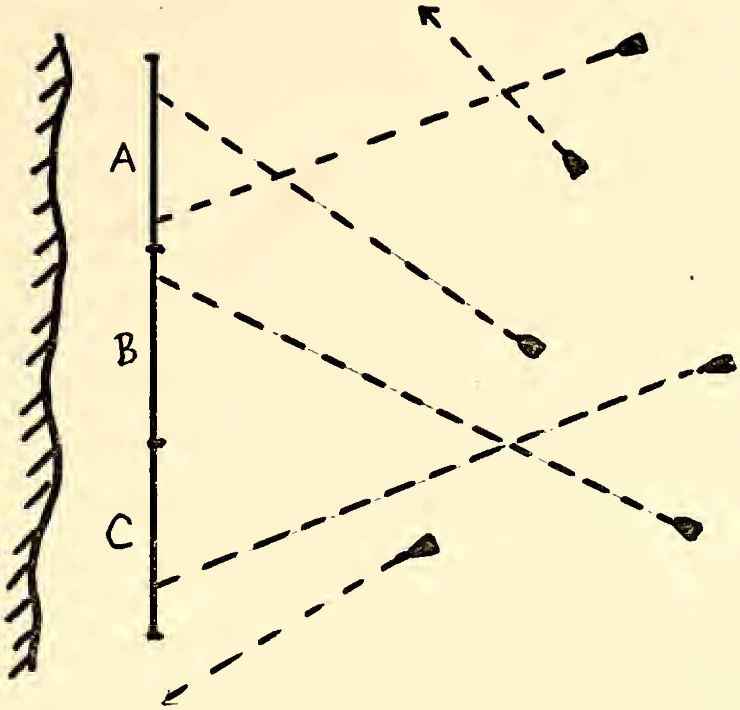


Figure A-2.

Suppose the aircraft depicted in Figure A-1 detected targets and that they were as shown in Figure A-2. Then there would be four potential insurgents and the *a priori* probability of the targets distribution are:

$$P_A = 2/4 = .5$$

$$P_B = 1/4 = .25$$

$$P_C = 1/4 = .25$$

where $P_A + P_B + P_C = 1.$

If it is estimated that targets will reach the barrier line at night, the air search should be conducted again in the evening to ensure that all such targets will be detected by the air search.

The *a priori* probability P_A, P_B and P_C could be obtained using information from other sources of intelligence.

B. PATROL TACTICS FOR A BARRIER PATROL

Suppose the line to be patrolled is 135 miles long and 12 miles off-shore. And suppose there are three ships available for patrolling at all times during the operation. The patrol line will then be divided into three barrier lines, A, B and C each of length 45 miles.

Now assume the searcher's speed V = 12 knots, the searcher's sweep width W = 20 miles and the target's speed U = 8 or 12 knots. (To simplify the analysis, the target's speed will be classified as 8 knots or 10 knots.)

Since P_A, P_B and P_C be the *a priori* probability that an incoming target will cross the barrier A, B or C, respectively, the probability of intercepting an incoming target is then

$$P(det) = P(det|A)P_A + P(det|B)P_B + P(det|C)P_C$$

where $P(det|A)$ is the probability of detecting a target, given the target is in A, etc.

The probability of interception depends on the patrol tactics used, and on the distribution of the incoming targets in the area. Tactics will be developed which maximize the probability of intercept by the barrier patrol.

1. <u>Barrier Search Model</u>

There are two types of barrier patrol; crossover patrol, and back-and-forth patrol [Ref. 23]. The probability

of detection for a crossover patrol will be assumed to be

$$P(\det) = \min \{1, \quad (1 + \frac{r\sqrt{r^2-1}}{r+1})/(\lambda+1)\} .$$

Hence, $\lambda = L/W$ where L is the patrol barrier length

and $r = V/U.$

For a back-and-forth patrol, the probability of detection will be assumed to be

$$P(\det) = \begin{cases} 1 - (\lambda - \frac{\sqrt{r^2+1}-1}{2})^2/\lambda(\lambda+1) & \text{for } r \leq 2\sqrt{\lambda(\lambda+1)} \\ 1 & \text{for } r > 2\sqrt{\lambda(\lambda+1)}. \end{cases}$$

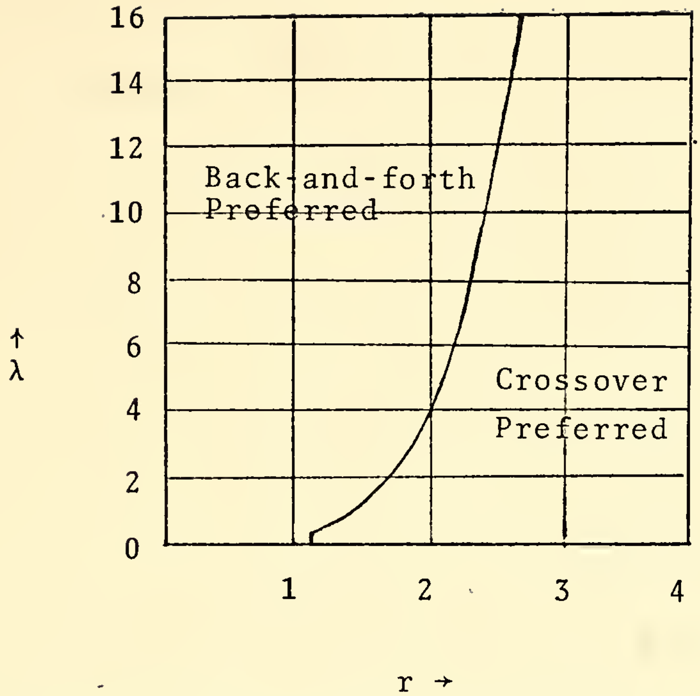
The type of patrol to be used in order to maximize intercept will depend on λ and r. By looking at the graph of Figure B-1, "Region of effectiveness of back-and-forth and crossover plan" [Ref. 23], which compares the probability of detection for these two types of patrols, the type of patrol to be used can be determined which maximizes the probability of detection.

a. Patrol Plans

The following patrol plans are based on the relevant barrier search models and the *a priori* probabilities associated with the targets. Target crossing points will be assumed to be uniformly distributed across a barrier segment.

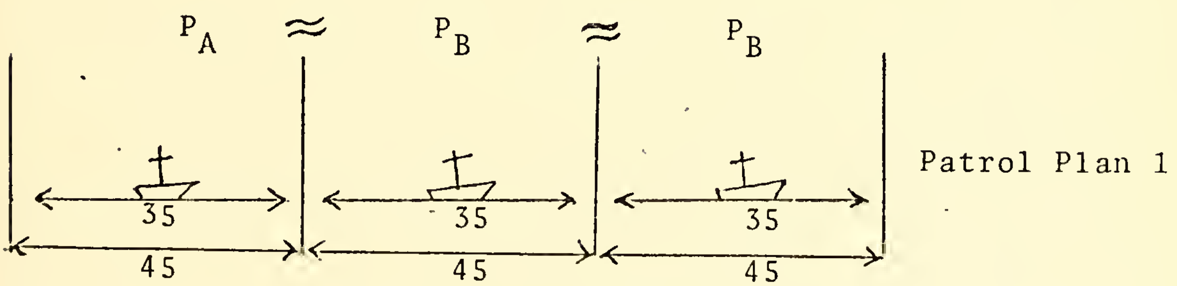
<u>Case I</u>

In this case, the probability of a target crossing barrier A is approximately equal to that of it



Region of effectiveness of back-and-forth and crossover plans.
Figure B-1.

crossing barrier B or barrier C. In this case, the search plan is indicated in the following Figure.



Distance in miles

The three barrier lengths are chosen to be 35 miles which provides an overlap of 5 miles at each end. Take, $P_A = P_B = P_C = 1/3$ and note $\lambda = 35/20 = 1.75$.

Given U = 10 knots, then r = 12/10 = 1.2, and one finds that a back-and-forth patrol is better than a crossover patrol. Now set

$$\overline{P} = P(\det|A) = P(\det|B) = P(\det|C),$$

then

$$\overline{P} = 1 - (1.75 - \frac{\sqrt{1.44 + 1} - 1}{2})^2/1.75(1.75+1$$

$$= .55.$$

And

$$P(\det) = \overline{P}\cdot P_A + \overline{P}\cdot P_B + \overline{P}\cdot P_C = .55(P_A + P_B + P_C)$$

$$= .55.$$

Given U = 8 knots, then r = 12/8 = 1.5, and again a back-and-forth patrol is better than a crossover patrol. Then

$$P = 1 - (1.75 - \frac{\sqrt{2.25 + 1} - 1}{2})^2/1.75(1.75+1)$$

$$= .62.$$

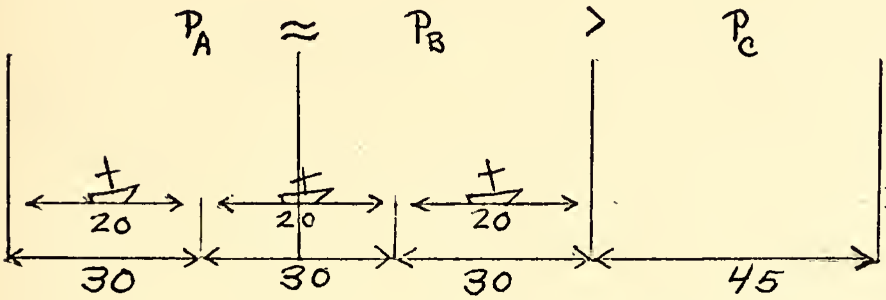
And

$$P(\det) = .62.$$

Case II

In this case, the probability of an incoming target crossing barrier A is approximated equal to that crossing barrier B and greater than that of crossing barrier C. It would be better to use three ships to patrol barrier A and B if the probability of intercept were greater than it would be if a single ship were assigned to each barrier as in the patrol plan of Case I which will be

called the 1st patrol plan. Whether or not this is so depends on the relative size of P_C compared to P_A and P_B. The new patrol plan which will be called the 2nd patrol plan is shown in the figure below.



Patrol Plan 2

Distance in miles

$$\lambda = 20/20 \doteq 1$$

Given U = 10 knots, then r = 12/10 = 1.2, and back-and-forth patrols are better than crossover patrols. Then

$$\overline{P} = 1 - \left(1 - \frac{\sqrt{1.44 + 1} - 1}{2}\right)^2 / 1(1+1)$$

$$= .74.$$

And

$$P(\text{det}) = P(P_A + P_B) = .74(P_A + P_B).$$

For the 2nd patrol plan to be better than the 1st one wants:

$$.74(P_A + P_B) > .55(P_A + P_B + P_C)$$

$$P_A + P_B > .55/.74 = .74.$$

So use the 2^{nd} patrol plan when $P_A + P_B > .74$ or $P_C < .26$ given U = 10 knots.

Given U = 8 knots, then r = 12/8 = 1.5, and crossover patrols are better than back-and-forth patrols, then

$$\overline{P} = (1 - \frac{1.5\sqrt{2.25-1}}{1.5+1})/(1+1)$$

$$= .84.$$

And

$$P(det) = .84(P_A + P_B).$$

For the 2^{nd} patrol plan to be better than the 1^{st} one wants:

$$.84(P_A + P_B) > .62(P_A + P_B + P_C)$$

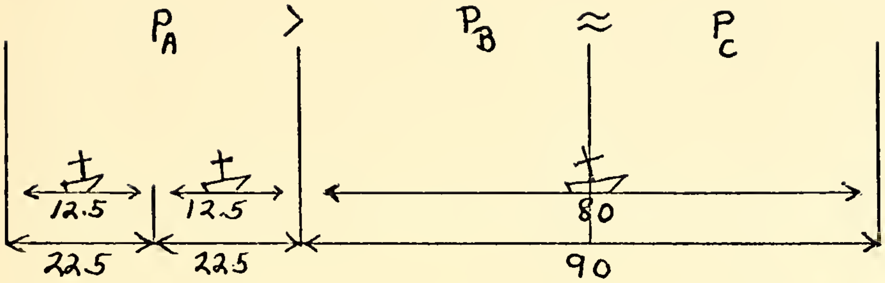
$$P_A + P_B > .62/.84 = .74$$

or

$$P_C < .26.$$

Case III

In this case, the probability of an incoming target crossing barrier A approximately equal that of crossing barrier B and is smaller than that of crossing barrier C. Suppose there are two ships which patrol in barrier A and one ship which patrols in barrier B and C, this will be called the 3^{rd} patrol plan. We will now find the value of P_A, P_B and P_C which will yield a probability of intercept for patrol plan 3 which is greater than that for patrol plan 1. Patrol plan 3 is shown in the following figure.



Patrol Plan 3

Distance in miles

Barrier A: Two patrol segments each 12.5 miles long with $\lambda_1 = 12.5/20 = .625$.

Barrier B: One patrol segment of 80 miles with $\lambda_2 = 80/20 = 4$.

Given U = 10 knots, then r = 12/10 = 1.2, and in barrier A crossover patrols are better while in barrier B plus C a back-and-forth patrol is better. Then,

$$\overline{P}_1 = (1 + \frac{1.2\sqrt{1.44-1}}{1.2+1})/(.625+1)$$
$$= .84.$$

And

$$\overline{P}_2 = 1 - (4 - \frac{\sqrt{1.44+1}-1}{2})^2/4(4+1)$$
$$= .31.$$

So $P(\text{det}) = \overline{P}_1 P_A - \overline{P}_2(P_B + P_C) = .84P_A - .31(P_B + P_C)$.

For the 3^{rd} patrol plan to be better than the 1^{st} patrol plan, one wants:

$$.84P_A + .31(P_B + P_C) > .55$$

$$.84P_A > .55 - .31(P_B + P_C)$$

$$P_A > .65 - .37(P_B + P_C)$$

$$1 > .65 - .63(P_B + P_C)$$

$$P_B + P_C < .35/.63 = .55$$

$$\text{or} \quad P_A > .45.$$

Given U = 8 knots, then r = 10/8 = 1.5, and in barrier A, crossover patrols are better while in barrier B plus C a back-and-forth patrol is better. Then

$$\overline{P}_1 = 1.$$

And

$$\overline{P}_2 = 1 - (4 - \frac{\sqrt{2.25+1}-1}{2})^2/4(4+1)$$

$$= .35.$$

So

$$P(det) = \overline{P}_1 P_A + \overline{P}_2(P_B - P_C) = P_A + .35(P_B + P_C)$$

For the 3^{rd} patrol plan to be better than the 1^{st} one wants:

$$P_A + .35(P_B + P_C) > .62$$

$$P_A > .62 - .35(P_B + P_C)$$

$$P_A + P_B + P_C > .62 - .35(P_B - P_C) + P_B + P_C$$

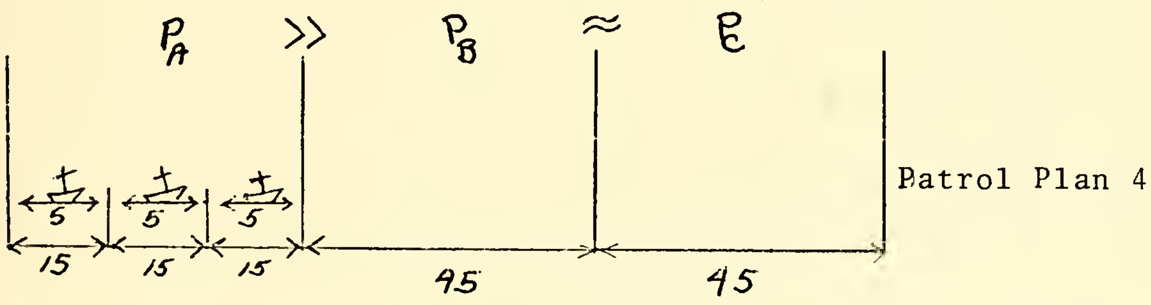
$$1 > .62 - .65(P_B + P_C)$$

$$P_B + P_C < .38/.65 = .58$$

$$\text{or } P_A > .42.$$

Case IV

When the density of the incoming target is nearly the same for A and B and these are much smaller than the density for C, use all three ships to patrol in barrier A. The patrol plan, called patrol plan 4 will yield a probability of interception greater than that for patrol plan 3 under the conditions developed below.



Distance in Miles

Barrier A: Three patrol segments, each = 5 miles long with $\lambda = 5/20 = .25$.

Given U = 10 knots, then $r = 12/10 = 1.2$, and in barrier A, crossover patrols are better. Then

$$\bar{P} = 1.$$

So

$$P(\text{det}) = \bar{P}P_A = P_A.$$

For the 4^{th} patrol plan to be better than the 3^{rd} patrol plan, one wants:

$$P_A > .84P_A + .31(P_B + P_C)$$

$$.16P_A > .31(P_B + P_C)$$

$$P_A > 2(P_B + P_C)$$

$$P_A + P_B + P_C > 2(P_B + P_C) + P_B + P_C$$

$$1 > 3(P_B + P_C)$$

$$P_B + P_C < .33$$

$$\text{or} \quad P_A > .67.$$

Given U = 8 knots, then r = 12/8 = 1.5, and crossover patrols are better in barrier A. Then,

$$\overline{P} = 1.$$

So

$$P(\text{det}) = \overline{P}P_A = P_A.$$

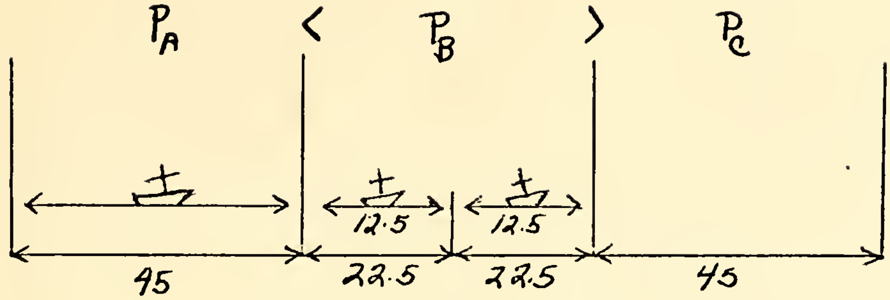
For the 4^{th} patrol plan to be better than the 3^{rd} one wants:

$$P_A > P_A + .35(P_B + P_C).$$

It is apparent that in this case, the 3^{rd} patrol plan is optimal, because two ships patrolling in this barrier gave a probability of intercept equal 1 already.

Case V

This case can be summarized by $P_A > P_B \simeq P_C$. The density of incoming targets is greater at the center of the barrier line. In this case, one may want to use patrol plan 5 which consists of two ships to patrol in barrier B, and the remaining ship patrolling in barrier A or C if this will yield a probability of intercept greater than that of the 1^{st} patrol plan.



Patrol Plan 5

Distance in Miles

Barrier A: 35 miles long with $\;_1 = 35/20 = 1.75$

Barrier B: Two segments each = 12.5 miles long with $\lambda_1 = 12.5/20 = .625$.

Given U = 10 knots, then r = 12/10 = 1.2, and in barrier A or C, a back-and-forth patrol is better while in barrier B, crossover patrols are better. Then,

$$\overline{P}_1 = 1 - (1.75 - \frac{\sqrt{1.44+1}-1}{2})^2/1.75(1.75+1)$$

$$= .55.$$

And

$$\overline{P}_2 = (1 + \frac{1.2\sqrt{1.44-1}}{1.2 + 1})/(.625+1)$$

$$= .84.$$

So,

$$P(det) = \overline{P}_1 P_A + \overline{P}_2 P_B = .55P_A + .84P_B.$$

For the 5^{th} patrol plan to be better than the 1^{st}, one wants:

$$.55P_A + .84P_B > .55$$

$$P_A > 1 - 1.53P_B$$

$$P_A + P_B + P_C > 1 - 1.53P_B + P_B + P_C$$

$$1 > 1 - .53P_B + P_C$$

$$P_C/P_B < .53 \text{ or } P_A/P_B < .53$$

$$P_C/P_B + P_A/P_B < 1.06$$

$$P_A + P_C < 1.06P_B$$

$$P_A + P_B + P_C < 1.06P_B + P_B$$

$$1 < 2.06P_B$$

$$P_B > 1/2.06 = .49.$$

Given U = 8 knots, then r = 12/8 ≐ 1.5, and in barrier A or C, a back-and-forth patrol is better while in barrier B, crossover patrols are better. Then

$$\overline{P}_1 = 1 - (1.75 - \frac{\sqrt{2.25+1}-1}{2})^2/1.75(1.75+1)$$

$$= .62.$$

And

$$\overline{P}_2 = 1.$$

So

$$P(\text{det}) = \overline{P}_1 P_A + \overline{P}_2 P_B = .62P_A + P_B$$

For the 5th patrol plan to be better than the 1st, one wants:

$$.62P_A + P_B > .62$$

$$P_A > 1 - 1.6P_B$$

$$P_A + P_B + P_C > 1 - 1.6P_B + P_B + P_C$$

$$.6P_B > P_C$$

$$P_C/P_B < .6 \text{ or } P_A/P_B < .6$$

$$P_C/P_B + P_A/P_B < 1.2$$

$$P_A + P_C < 1.2P_B$$

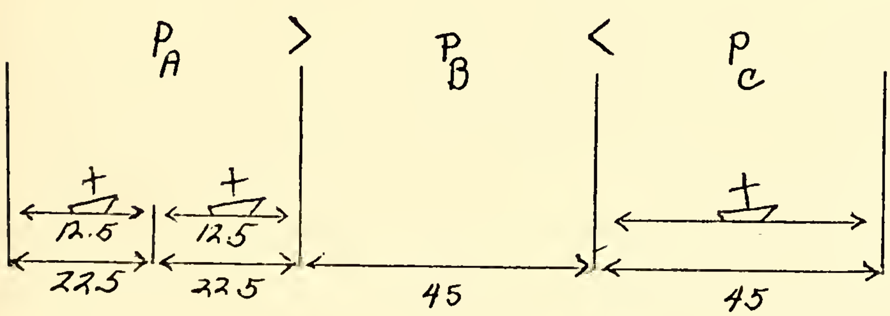
$$P_A + P_B + P_C < 1.2P_B + P_B$$

$$1 < 2.2P_B$$

$$P_B > 1/2.2 = .45.$$

Case VI

This case can be summarized by $P_A \simeq P_C > P_B$. When the density of incoming targets is smaller at the center of the barrier line, one should shift the patrol ship from barrier B to barrier A or C rather than use plan 1 if P_B is smaller than the value found below. This will be called patrol plan 6.



Patrol Plan 6

Distance in miles

The condition for using plan 6 is found in the same way as in Case V.

Given U = 10 knots. Then,

$$P_A/P_B \quad P_C/P_B > 1/.53.$$

So
$$P_C/P_B + P_A/P_B > 2/.53$$
$$P_A + P_C > 2P_B/.53$$
$$P_A + P_B + P_C > 2P_B/.53 - P_B$$
$$1 > 2.53P_B/.53$$
$$P_B < .53/2.53 = .21.$$

Given U = 8 knots. Then,

$$P_C/P_B \quad P_A/P_B > 1/.6$$

So
$$P_A/P_B + P_C/P_B > 2/.6$$
$$P_A + P_C > 2P_B/.6$$
$$P_A + P_B + P_C > 2P_B/.6 - P_B$$
$$1 > 2.6P_B/.6$$
$$P_B < .6/2.6 = .23.$$

Case VII

This case is summarized by $P_A > P_B > P_C$ or $P_B > P_C > P_A$ or $P_C > P_A > P_B$ etc. In this case, one should shift the patrol ship from C to A under the same conditions as in Case V, i.e.

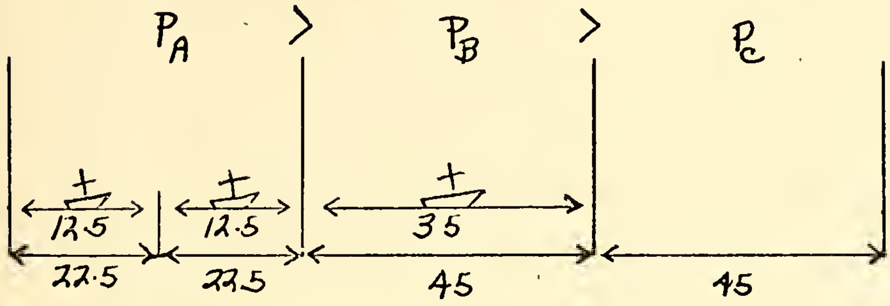
$$P_A/P_C > 1/.53 = 1.9, \text{ for } U = 10 \text{ knots},$$

with
$$P(det) = .84P_A + .55P_B;$$

and
$$P_A/P_C > 1/.6 = 1.7, \text{ for } U = 8 \text{ knots},$$

with
$$P(det) = P_A + .62P_B.$$

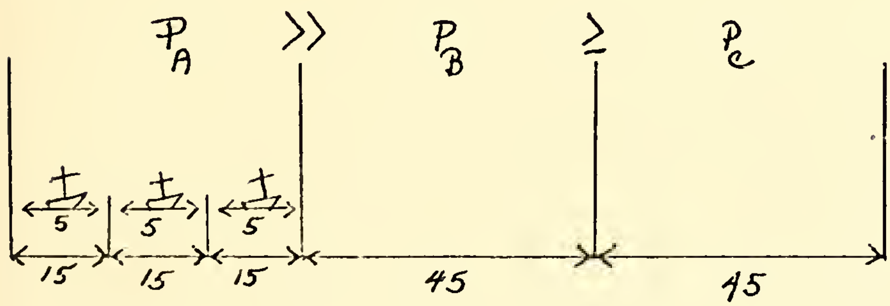
The modified patrol plan will be called plan 7 and it is shown in the following figure.



Patrol Plan 7

Distance in miles

The patrol ship in B should be shifted to A as shown in the following figure when P_B satisfies the conditions shown below. The patrol plan will be called plan 8.



Patrol Plan 8

Distance in miles

Given U = 10 knots, then r = 12/10, and a cross-over patrol should be used. Then,

$\overline{P} = 1.$

So

$$P(det) = \bar{P}P_A = P_A.$$

For the 8^{th} patrol plan to be used, one wants:

$$P_A > .84P_A + .55P_B$$

$$.16P_A > .55P_B$$

$$P_A/P_B > 3.4.$$

The plan should also be applied in the case $P_B \approx P_A \approx P_C$ with appropriate modification when $P_B/P_A \approx P_B/P_C > 3.4$.

Given U = 8 knots. Then, r = 12/8 = 1.5, and a crossover patrol is best. Then

$$\bar{P} = 1.$$

So

$$P(det) = \bar{P}P_A = P_A.$$

To use plan 8, one wants:

$$P_A > P_A - .62P_B.$$

It is apparent that in this case, one would never use a three ship patrol in a same barrier because a two ship barrier in A and one ship barrier in B will yield a higher probability of interception.

2. Table for Patrol Plans

The patrol plans and the condition for these use Tables I and II, the tables are designed to be used by a decision maker or patrol 3 group commander to determine how to deploy these patrol ships, when the target density across a barrier is assumed to satisfy the specified conditions

distribution. The targets are classified into two classes, low speed targets with speeds of approximately 8 knots, and high speed targets with speeds of approximately 10 knots. In each case, the following values have been used in computation.

Patrol craft's speed	$V = 12$ knots
Sweep width	$W = 20$ miles
Overlap at the end of each barrier	$= 5$ miles

$P_A + P_B + P_C = 1$ with the densities constant in each sector.

It has been assumed that there will always be three ships available for patrol during the time of operation.

For other than three ships, patrol plans could be established by using the same procedures as were used here.

Table I. Patrol Plans for Target Speed 10 Knots.

A Priori Probability of target crossing barrier segment	Patrol Plan Recommended	Probability of Interception
$P_A \approx P_B \approx P_C$	1	.55
$P_A \approx P_B > P_C$ (or $P_B \approx P_C > P_A$) $P_C < .26$ (or $P_A < .26$)	2a	$.74(P_A + P_B)$ (greater than plan 1)
$P_A > P_B \approx P_C$ (or $P_C > P_B \approx P_A$)		
1. $P_A > .45$ (or $P_C > .45$)	3	$.84P_A + .31(P_B + P_C)$ (greater than plan 1)
2. $P_A > .67$ (or $P_C > .67$)	4	P_A (greater than plan 3)
$P_B > P_A \approx P_C$		
1. $P_B > .49$	5	$.55P_A + .84P_B$ or $.55P_C + .84P_B$ (greater than plan 1)
2. $P_B/P_A \approx P_B/P_C > 3.4$	4	P_B (greater than plan 5)
$P_A \approx P_C > P_B$ $P_B < .21$	6	$.84P_A + .55P_C$ or $.84P_C + .55P_A$ (greater than plan 1)
$P_A > P_B > P_C$ (or $P_B > P_C > P_A$)		
1. $P_A/P_C > 1.9$ and $P_A/P_B \leq 3.4$	7	$.84P_A + .55P_B$ (greater than plan 1)
2. $P_A/P_C > 3.4$	6	P_A (greater than plan 5)

Note: See Appendix for description of patrol plan

Table II. Patrol Plan for Target Speed 8 Knots.

A Priori Probability of target crossing barrier segment	Patrol Plan Recommended	Proabaility of Interception
$P_A \approx P_B \approx P_C$	1	.62
$P_A \approx P_B > P_C$ (or $P_B \approx P_C > P_A$) $P_C < .26$ (or $P_A < .26$)	2b	$.84(P_A + P_B)$ (greater than plan 1
$P_A > P_B \approx P_C$ (or $P_C > P_B \approx P_A$) $P_A > .42$ (or $P_C > .42$)	3	$P_A + .35(P_B + P_C)$ (greater than plan 1)
$P_B > P_A \approx P_C$ $P_B > .45$	5	$.62P_A + P_B$ (greater than plan 1)
$P_A \approx P_C > P_A$ $P_B < .23$	6	$P_A + .62P_B$ or $P_C + .62P_B$ (greater than plan 1)
$P_A > P_B > P_C$ $P_A/P_C > 1.7$	7	$P_A + .62\ P_B$ (greater than plan 1)

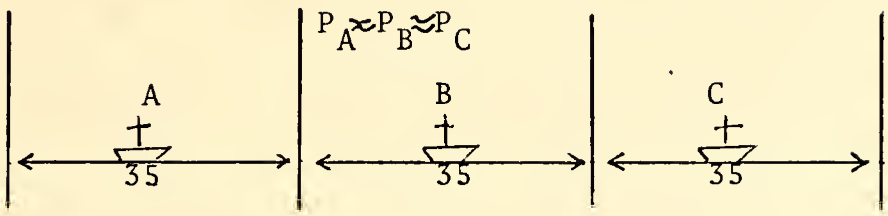
Note: See Appendix for description of patrol plan.

VI. CONCLUSION

Patrolling coastlines against infiltration by sea is one of the problems of developing countries. Six insurgency cases studied from the past suggest that if government forces can control supply from the sea, then the government forces will be victorious but if government forces cannot control supply from the sea, then the insurgent forces will be victorious. Most developing countries are short of patrol crafts. However, some have PGMs which were transferred from the United States Navy under the Military Assistance Program. They are suitable for patrol against unconventional and guerilla warfare. This paper's intent is to show how to maximize the utility of these patrol crafts in barrier patrol operations. Appendix A is a summary of patrol plans for counter-insurgency infiltration from the sea.

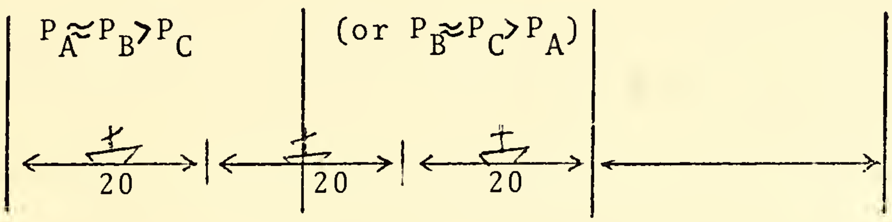
APPENDIX A: DESCRIPTION OF PATROL PLANS

Plan 1



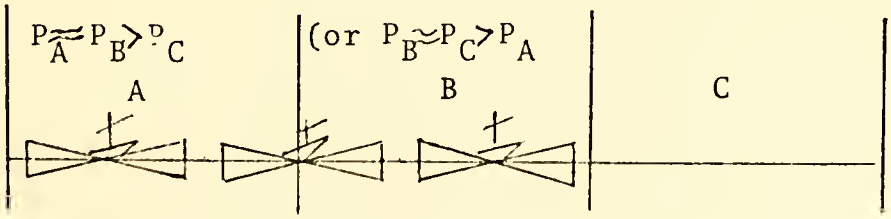
Each ship patrols back-and-forth in each barrier with equal search length of 35 miles.

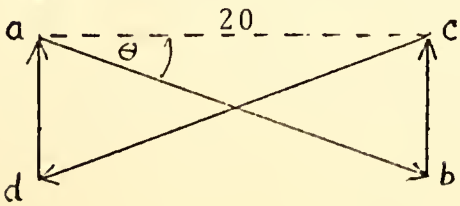
Plan 2a



Three ships patrol back-and-forth in two adjacent barrier (A,B or B,C) with equal search length of 20 miles each.

Plan 2b





Symmetric Crossover Patrol [Ref. 2

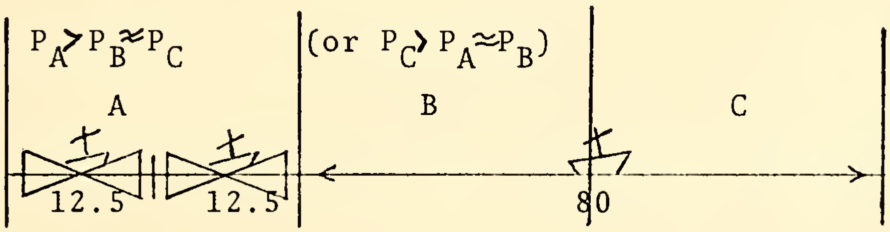
$\theta = \sin^{-1} U/V$

$ab = 20 \sec\theta = cd$

$bc = 20 \tan\theta = da$

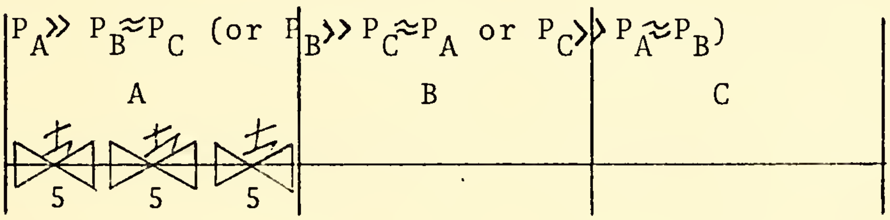
Three ships patrol with crossover patrol in two adjacent barrier (A,B or B,C) with equal search lengths of 20 secθ miles.

Plan 3



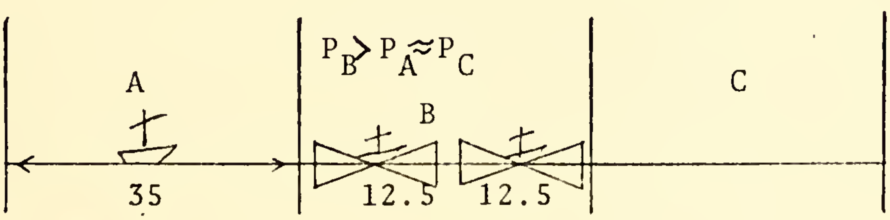
Two ships use a crossover patrol in one barrier with equal search length 12.5 secθ miles each and the remaining ship use a back-and-forth patrol in the remaining adjacent barrier with search length of 80 miles.

Plan 4



Three ships crossover patrol in one barrier A, B or C with equal search length 5 secθ miles each.

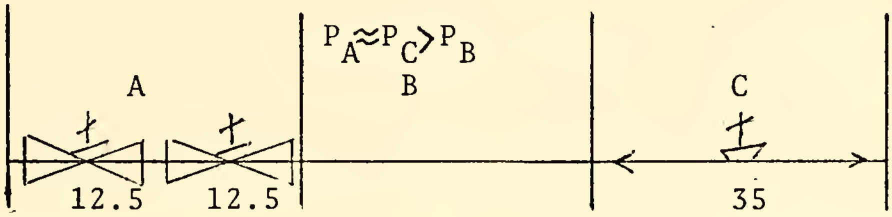
Plan 5



Two ships use a crossover patrol in barrier B with equal search length of 12.5 secθ miles. The remaining ship

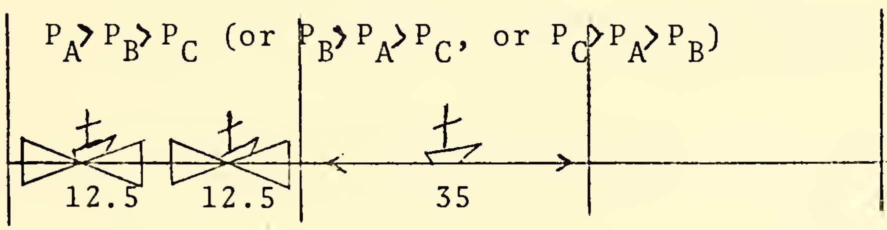
uses a back-and-forth patrol in barrier A or C with a search length of 35 miles. (The remaining ship patrols in A or C by randomly choosing A or C in each period, e.g., flip a coin, draw a random number, etc.)

Plan 6



Two ships use a crossover patrol in barrier A or C with equal search length 12.5 secθ miles and the remaining ship uses a back-and-forth patrol in barrier A or C with search length of 35 miles. Barrier A or C are randomly chosen as in plan 5.

Plan 7



Two ships use a crossover patrol in the barrier with the greatest probability density with equal search lengths of 12.5 secθ miles the remaining ship uses a back-and-forth patrol in the remaining barrier with a search length of 35 miles.

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