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LAND SEARCH THEORY

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To Whom it May Concern:

The Pennsylvania Wing, Civil Air Patrol endorses this revision of the Ranger Team Commanders Notebook. Team Commanders Notebook # 3 has been approved for distribution through out the Wing. It is the approved guidance for Land Search and Rescue in Pennsylvania.

This third revision of this manual supersedes all other additions. This Team Commander's Notebook (TCN) has undergone a complete review resulting in many updates over the older versions.

This third edition, dated July 2005 is authorized and approved for the use of all Pennsylvania Wing Ground Search and Rescue Teams / Ranger Teams.

M. Allen Applebaum. Colonel, CAP
Commander

UPI – 17 October 1966

> **"The body of a 3-year-old boy, missing for 30 hours, was found trapped in a swamp late Thursday night, his arms still clinging desperately to firm ground.**
>
> **A medical examiner said little Frederick A. Banks of Greenwich, Conn. had been dead about 9 hours.**
>
> **The child's body was found half a mile from his home after police and 700 volunteers had scoured the area with dogs, horses and helicopters.**
>
> **Searchers struggled for 30 minutes to free the body from a slime-filled crevice between two parts of solid earth.**
>
> **Frederick wandered away from his home at dusk on Wednesday."**

* * * * * * * * * * * * * * * *

The above newspaper account, terse as it is, cannot help but move deeply anyone who has ever taken part in a search. It is my sincere hope that the publishing of this article on **Land Search Theory** may prevent at least one such tragedy in the future. Although I was not present and do not know all the details of this particular search, I have seen similar efforts by large groups of well-meaning volunteers. It is our experience in the Pennsylvania Civil Air Patrol that the job can be done better by a small group of trained searchers – indeed, it will be shown later in this article that a twelve-man search team, applying the principles contained in this article, might well have found the missing boy in time to save his life.

Whenever you, as a searcher, feel your enthusiasm getting low at the end of a day of searching the bush, please do as I do and conjure up the picture of this three-year-old boy clinging desperately to the firm ground and waiting for the help that never came.

Thomas E. Jensen
Lt Col CAP

About the author: Lt Col Jensen has BS and MS degrees in Chemistry from Lehigh University. He served 2 years in the US Army Ordnance Corps as a Technical Intelligence Specialist. After a variety of technical jobs, the last 27 years of his professional career were spent as a Forensic Scientist (& Supervisor) in the Pennsylvania State Police Crime Lab system. He has been active in CAP Ground Search and Rescue since 1963, holds the Expert Ranger rating, and co-authored **Land Search and Rescue, Part One** (the Ranger Training Manual) in 1969. **Land Search Theory** has served as the primary text for the Search Theory classes he has taught at the Hawk Mountain Ranger School since 1970.

LAND SEARCH THE0RY

INTRODUCTION

A Ranger Team Commander may be called upon at any time to plan and organize a search for a missing person. In 1970, a few texts were available which discussed some of the factors which go into planning a search – but most of those were concerned with a field commander's immediate problems of management (communications, rescue techniques, search patterns, etc.) Very little was available to aid the commander who asks "What is the most effective method of searching?" As a result, much planning of searches was done using past experience and common sense as the only guides. Often, plans based on these guides were basically sound, but sometimes a search situation was encountered where these guides were not sufficient. Since 1970, when the first edition of this notebook was published, other authors have treated various aspects of search theory, but the basic material in this publication is still valid. The terminology invented for the first edition has been replaced in common practice, and the newer terminology will be used in this second edition (2005).

It is the aim of this article to show how to critically analyze search problems and apply certain rules that will be developed on a logical basis. Some general guidelines are included on the back cover to serve as memory joggers when planning a search, but no iron-clad "method" is included for running each search. The article is intended instead to develop a way of thinking in those who study it. For most people, this article will not be the answer to all their questions on search planning but merely a starting place in their search for knowledge in this area. It will be found to be especially effective when used as a study supplement to a course given by someone who is already familiar with probability theory.

PROBABILITY AND SEARCH THEORY

Introduction

It will be necessary here to introduce a small amount of mathematics in talking about probability. To begin, all probabilities will be expressed as decimals – that is, a 50% probability will be written as 0.50, a 25% probability as 0.25, and a 100% probability as 1.00. Note that 1.00 represents the upper limit, and is rarely reached in fact.

In addition, we will now define three terms – all of them probabilities:

> **POD** is the probability that the searchers will make a find if they "encounter" the target – that is if the target is directly in their search path. (Probability of Detection)
>
> **POA** is the probability that the target is located in the path of the search – i.e. the target is in the Area being searched. (Probability of Area)
>
> **POS** is the total probability that the searchers find the target. (Probability of Success)

From probability theory we can show that:

> **POS = POD x POA (for a simple situation.)**

To give a concrete example, if we have a probability of 0.80 that the searchers will make a find given an encounter, and a probability of 0.50 that the target is in the path of the search, the total probability of success is:

POS = 0.80 x 0.50 = 0.40; or a 40% chance of success.

The above situation describes a single search of an area. When an area is to be searched more than one time, the situation is more complicated. The combined probability of success is given by the formula:

$$\mathbf{P_n = 1 - (1 - P_1)^n}$$

where $\mathbf{P_n}$ is the probability of success after **n** searches where each search had a probability of success of $\mathbf{P_1}$.

This is difficult to visualize, and can best be seen by calculating not the probability of success, but rather the probability of failure.

$$\mathbf{P_{failure} = (P_{failure\ of\ a\ single\ search})^n}$$

The probability of success can then be calculated by subtracting the probability of failure from 1.00 since the two probabilities must sum to unity. (No other result is possible; there will certainly be either success or failure.) Thus, if **POS** for a single search is 0.90, the probability of failure is 0.10; the probability of failure for two successive searches is $(0.10)^2$ or 0.01 and the probability of success for the two searches is 0.99. There is one thing to be very wary of here though – this applies only to planning before hand. If the target is known to be in the search area, and one search has already failed to find it, the probability of finding it on the second search is not 0.99 (in the example above) but is still 0.90 (**POS** for a single search). The probability calculated for the two searches is the probability of finding the target at least once if the area is to be searched two times.

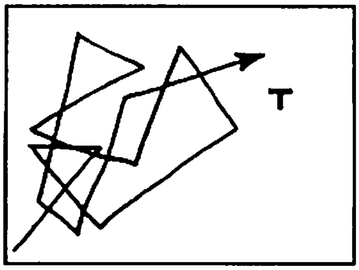
To facilitate the calculation of multiple-search probabilities for those who are not mathematically inclined, **Table 1** on the back cover contains a set of probabilities worked out for some common values.

Random Versus Orderly Searches

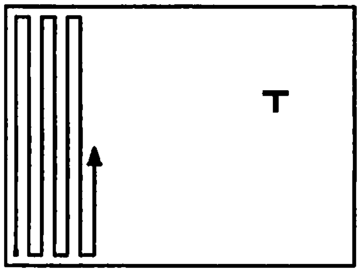
Rule: An orderly, planned search of a given area is more efficient than a disorganized, random search.

The above rule may seem to be trite, but the process by which it is derived is of interest. Consider an area **A** in which a search target **T** is located. If the searcher wanders around **A** in a random fashion, he may stumble upon **T** right away or he may crisscross the area for weeks before finding **T**. Probability theory tells us that he will be certain of finding **T** if he searches long enough. (See illustration.) The disadvantage of a random search is that the same spot may be searched two, three, or more times (see areas where the searcher's trail crosses itself) while other spots may go unsearched. Every time the searcher retraces his steps or crosses his previous search paths, he is searching that area twice.

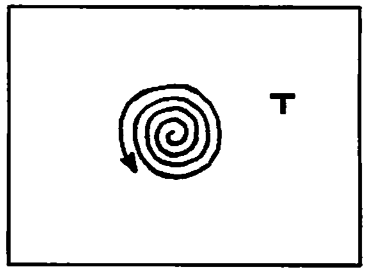
In fact, the longer he remains in **A**, the more frequently he is crossing previous search paths and the less efficient his search becomes.



Random Search



Creeping Line Search



Expanding Spiral Search

An orderly search of **A** is a search following a preset pattern that does not permit retracing paths and is designed to cover the entire area. Two examples of orderly search patterns are illustrated: the Creeping Line and the Expanding Spiral. Both of these patterns will cover the entire area without crossing or retracing previous search paths. In land search operations, the creeping line pattern is often used because the navigation necessary for a searcher or search team to follow the pattern is simpler than that required for the expanding spiral. Note that if **POD** and **POA** both equal 1.00, then **POS** will equal 1.00 for a single, complete search of the orderly type. **POS** for the random search, however, will equal 1.00 only after an infinitely long searching time.

Areas of Uniform Probability

Rule: Search the entire area once before re-searching a portion already searched.

This rule may also seem trite, but again the logic on which it rests is informative.

Consider the case where the target **T** is known to be in area **A** but no information is available to indicate that any one portion of **A** is more likely to contain **T** than any other portion of **A**. Assume also that **POD** is less than 1.00. (This can be due to the size of **T** and/or the nature of the terrain.) Let us assume for illustration that **POD** is 0.80. Let us now ask the question, "After searching one-half of **A**, what is the probability that we will have made a find?" Since **A** is a uniform probability area, **POA** is equal to the fraction of **A** that was searched (0.50) and:

$$\textbf{POS} = 0.80 \times 0.50 = 0.40$$

After searching all of **A**, the probability that **T** will have been found is:

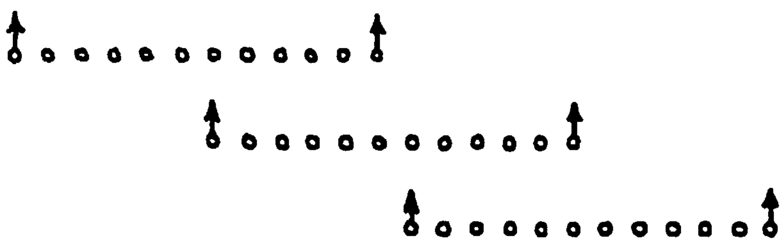
$$\textbf{POS} = 0.80 \times 1.00 = 0.80$$

If, however, after searching one-half of **A** we were to search that same half over again, the total probability of success for the two searches would be 0.48. Table 1 gives us a **POD** of 0.96 for two searches, each at a **POD** of 0.80, and since we are covering only half the total area:

$$\textbf{POS} = 0.96 \times 0.50, \text{ or } 0.48$$

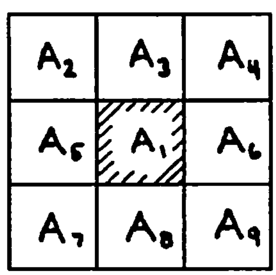
Note that **POS** cannot exceed 0.50 as long as we plan to search the first half twice. Since it takes just as long to search one-half **A** twice as it does to search all of **A** once, but **POS** is 0.48 in the first case and 0.80 in the second case, we would naturally prefer the plan with the higher probability of success.

One thing that must be guarded against is hidden ways in which the rule stated here may be violated. One such case occurred in 1965 south of Harrisburg, Pennsylvania. A control surface suddenly came off the tail assembly of a Lockheed Jetstar while in flight, with the pilot narrowly averting a crash. The pieces of the tail were scattered over an area approximately 1 mile by 4 miles with the pieces ranging in size from one inch across to one foot across. The terrain was mixed farmland and woodland. To make matters worse, the pieces were painted sort of grass-green on one side. The FAA made it clear that recovery of the tail assembly was of the utmost importance, and a search crew of approximately 200 Rangers was assembled for one of the weekend phases of the search. Enough of the pieces were eventually recovered to allow the engineers to reconstruct the cause of the accident, but the following error in technique was committed: In order to increase **POD** (although we didn't think of it in those exact terms then) it was ordered that the search teams would make a creeping line search in their own assigned grid areas, and instead of using three teams in one long search line, the individual teams would advance in echelon with 50% overlap in coverage by teams. (See illustration.) Although this did raise **POD** from perhaps 0.80 to 0.96 (see **Table 1**) the size of the search area was such that only about one-third of the area was covered that weekend. **POS** could have been almost doubled by eliminating the overlap and covering more area instead of being increased by less than 20%.



Skirmish Teams in Echelon with 50% Overlap.
(An example of double-coverage before complete single-coverage.)

Areas of Non-Uniform Probability



Nine Square Problem

Let us now assume that we have a square area **A**, containing a target **T**; that **A** is subdivided into nine equal squares **A_1, A_2, ...** **A_9**, and that there is a higher probability that **T** is in the central square (**A_1**) than in any of the other squares. (One reason for assuming a higher probability for the central square could be that it contains the "Point Last Seen" or "**PLS**".) The other squares are assumed to all have equal probabilities of containing **T**.

Obviously the first area to search is **A_1** (it yields a higher **POS** per amount of time spent searching than the other areas), but the question arises after one fruitless search of **A_1**, "Do we search **A_1** again, or go on to one of the other areas?" The answer to this question depends on two factors:

1. The probability that **T** is in **A_1** (as initially estimated), and
2. The thoroughness of the search (**POD**) of **A_1**.

There are two basic ways to answer this question. One way is to say that the fruitless search changed the probability that **T** is actually in **A_1** and attempt to recalculate all the sub-area **POA** figures. This method has come into some use in the time since 1970, but seems unnecessarily complex, and can lead one to lose sight of probabilities after several recalculations. The preferred method here is to look at the search efficiency (increase in **POS** per unit time) for a second search and compare it to the first-search efficiency of any of the other areas.

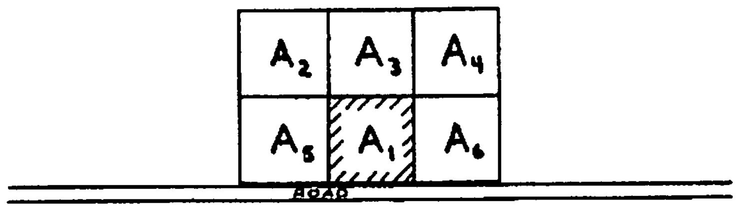
Let us look at an example. Assume that **POA** for **A_1** is twice as great as for any one of the other sub-areas. Since there are nine total sub-areas and one of them counts for two, that makes **POA** for **A_1** equal to 0.20, with 0.80 left to be evenly distributed among the other eight sub-areas, or 0.10 per sub-area. (**POA** for all the sub-areas sums to 1.00 since it is assumed that the target is somewhere in the overall area.) Let us assume that **POD** for this search is only 0.50 and that we have searched **A_1** one time without success. From **Table 1** we see that a two-search strategy at 0.50 each, gives an overall **POD** of 0.75 and that the difference in **POS** between the one-search and two-search strategies for **A_1** is:

two-search	$0.75 \times 0.20 = 0.15$	
one-search	$0.50 \times 0.20 = \underline{0.10}$	
	difference $= 0.05$	= benefit from second search of **A_1**.

This difference in **POS** is the same as for a first search of any one of the other sub-areas ($0.50 \times 0.10 = 0.05$). Since the areas are the same size, either strategy will yield the same increase in accumulated **POS** for the same time/effort expenditure. Therefore, **in this particular case,** it does not matter whether a second search of **A_1** or a first search of any of the other sub-areas is undertaken. Note how the final decision is dependent on **POD** and **POA**.

(Using the recalculation of **POA** method, we would say that 50% of the time **T** was in **A_1** we would not find **T**. Therefore, after one fruitless search, the probability that **T** is indeed in **A_1** is 0.50 times the original probability (0.20) that it was there. This leads to a new **POA** for **A_1** of 0.10 which is equal to that of each of the other sub-areas. The effect on our decision is the same.)

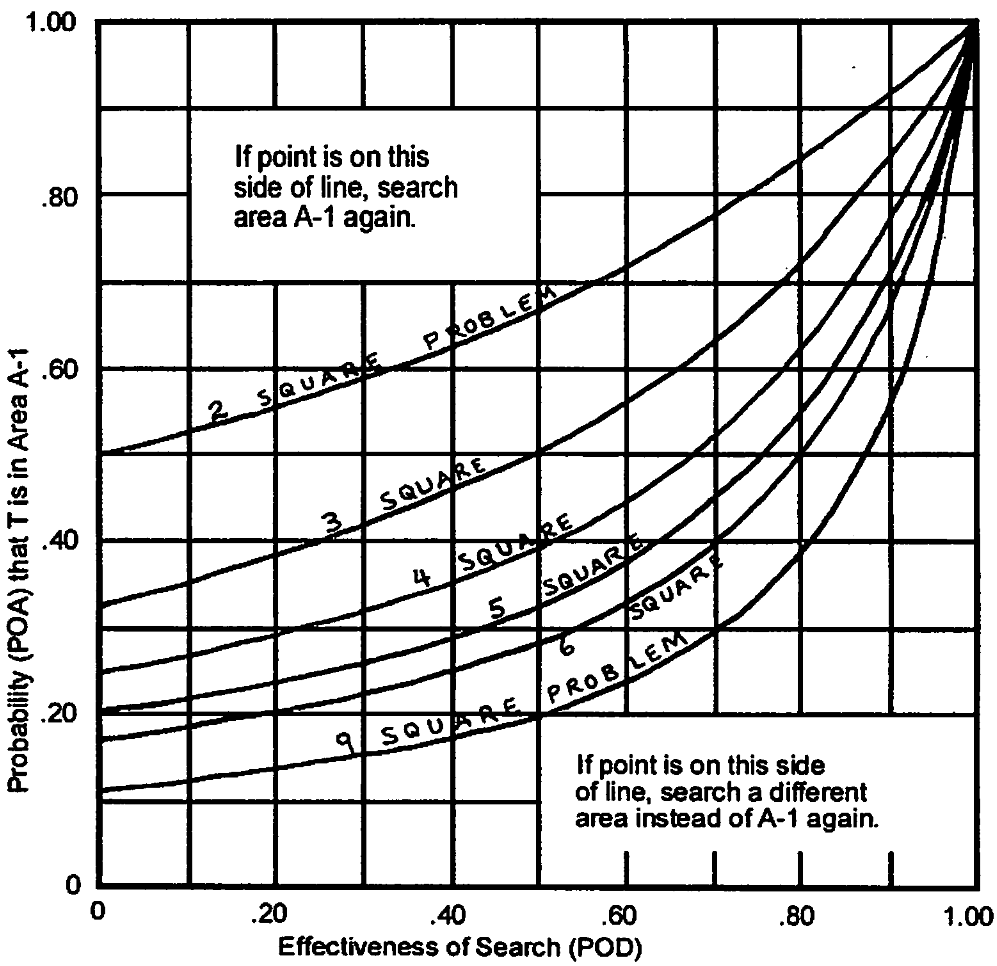
The above case is one that I call a "nine square problem" because the area is subdivided into nine squares. It may be useful where searchers have a "last reported seen at ....." position (commonly abbreviated as "**PLS**" for "Point Last Seen") to start from. Sometimes there are physical terrain features that make a smaller number of squares possible. For example:



Six Square Problem

Here the target was last seen in **A_1** and it is known that he did not cross the road. **A_1** is the area of highest probability out of a total area of six squares.

To aid in decision making, a graph has been prepared for 2, 3, 4, 5, 6, and 9 square problems. Merely decide on values for **POD** and **POA** (for **A_1**), locate these values on the axes of the graph, and see on which side of the line for your particular problem the point of their intersection falls.



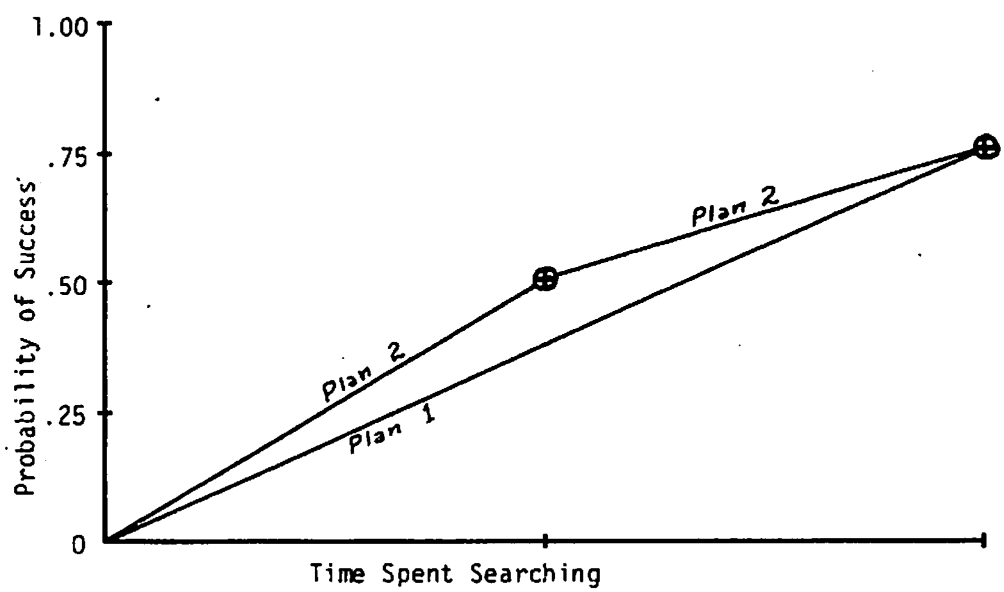
One conclusion that can be drawn from a study of the graph is that for **POD** values of 0.80 or higher, it takes unusually high **POA** values for **A_1** to justify searching **A_1** a second time.

The search problem exemplified by the nine-square problem can also be tackled by an expanding spiral search starting at the point where the target was last seen. Analysis of this problem to determine the point where the spiral should be abandoned and the central portion searched again is beyond the scope of this article. The "Square" problems are useful in illustrating the method of solution, and also because the expanding spiral type of search is beyond the navigational capabilities of many search teams.

Speed of Searching

POD depends on many factors. Some of these, such as speed of walking, and distance between searchers in the skirmish line, not only affect **POD**, but also the rate at which search area is covered. Thus we are going to have to compromise between high probability of a find given an encounter, and high probability of an encounter. Another way of saying it is that we have to balance *speed* and *thoroughness* in our search.

Let us again consider a concrete example that will illustrate a useful technique of planning, and present an interesting conclusion. Consider an area **A** containing a missing person target **T**. The area is large and has much ground cover. Two days are available for the search. The search commander estimates that in the time available, his team can search **A** once with a slow, thorough search at a **POD** of 0.75, or they can search the area twice with two faster, looser searches, each at a **POD** of 0.50. **Table 1** shows that the second plan gives a combined **POD** of 0.75 which is the same as that for the first plan. Since **POA** is assumed to be 1.00, **POD** = **POS** and there does not appear to be any difference between the two plans in terms of final results. Let us examine, however, a graph showing **POS** versus **Time**.



Since the area is assumed to be of uniform probability, **POS** increases linearly with time (i.e. with the amount of area searched). This holds for any one search of the area. **Plan 1**, the single search, shows a steady increase of **POS** with time up to the maximum value of **0.75**. **Plan 2**, the double search, shows a straight-line increase to a **POS** of **0.50** at the end of the first day, and another straight-line increase at a slower rate for the second day of the search to a final value of **0.75** (the same ending point as Plan 1).

Observe that **Plan 2** gives higher values of **POS** early in the search than does **Plan 1**. This can be very important where the target is such that an early find is imperative. It is not contended that all searches should be fast ones, but rather that the search commander should try to estimate **POD** for different speeds of searching and see what effect this has on rate of increase of **POS** with time.

GAME THEORY AND SEARCH TECHNIQUE

One technique used in the mathematical discipline of Game Theory can well be applied to search situations. This is the concept of maximizing the payoff of the game (the search). In a sense, we have been doing that in the first section of this article by adopting strategies that gave higher **POS** values. What we shall do now, however, is to consider some of the other factors that go into "payoff" beyond the mere fact of making a find of the target.

Early Finds

In the section on speed of searching, we touched on the question of early finds. Question: Is an early find "better" than a later find? From the standpoint of the searchers, the only difference is that they get to go home earlier. From the standpoint of the target, however, it could be the difference between life and death (see the UPI article on the inside front cover). Therefore, we can say that a plan that produces a high probability of an earlier find has a better payoff than some other plan. How much better? It is difficult to quantify these factors to include in a planning session.

Condition of Target

Above, we talked of early finds being good if the target is in danger during the time he is lost. There are times when this danger can be estimated from known factors:

- A lost diabetic person without insulin supplies will surely perish in a short time - perhaps one or two days – where a healthy person could survive for weeks.
- A small child has little survival sense and is in danger from the elements, the terrain, and his own panic. (Many lost children will deliberately hide when searchers approach because they are afraid of the searchers or of punishment for the actions that lead to their being lost.)
- Weather or terrain can be so unfavorable as to make survival by any person difficult.

When these factors are known, they definitely must be taken into account in planning the search.

When these factors are NOT known, it still may be possible to take the condition of the target into account in planning the search. Consider the case of a lost hunter in a given area. The hunter is known to be reasonably healthy (when last seen) and lost (missing) in an area bounded by roads so that if he walks out to them he will be safe. In planning the search, even though we do not know what his condition is, we can make one of three possible assumptions about the target:

A. He is alive and well. Either he will walk out, or sit until found.

B. He is injured (or ill) and immobile. He must be found or he will die. Since he is injured and the weather is cold, he will perish of exposure if not found in a short time (talk to doctors about this).

C. He is dead. (He is also, therefore, immobile and will wait for you to find him.)

First, purge your mind of any payoff considerations that only affect the comfort of the searchers. (Searches planned around payoffs that include hot showers, pleasant working hours, etc. are to be discarded.) Next, consider how the three possibilities affect the payoff of the search.

A. (Alive and well). Either he will walk out (does not affect searcher's plans) or you will find him. This will do him a small service, giving a small positive payoff.

B. (Injured). You will (1) find him in time to save his life, which gives a large positive payoff, or (2) too late to save his life, which gives either no payoff or a negative payoff (depending on press reports, psychological effect on searchers, etc.) or (3) you will not find him, with approximately the same payoff as (2).

C. (Dead). You will find him or not. Time is not important, and neither is finding him. The only payoff is to comfort the relatives and let the searchers stop the search - i.e. very small payoff.

Note that although we have no knowledge of the actual physical condition of the lost hunter, only one of the three possibilities gives the promise of a large payoff – the one where we assume that he is injured and that it is necessary to find him quickly. <u>Therefore, the search should be planned on this assumption.</u>

As before, this is not offered as a general rule to follow: i.e., "always assume he is injured", but rather as an example of the type of planning that should go into a search. In its simplest form, Game Theory is just the method of examining all the possibilities and seeing how each possible situation affects the outcome of the game. The above was such an example.

<u>Negative Payoff</u>

Brief mention of possible negative payoff was made above. Negative payoff is where one winds up in a worse position at the end of the game (search) than at the beginning. An example of that occurred several years ago in Catasauqua, Pennsylvania when a Scuba diver was trying to recover the body of a boy who had fallen through the ice on a canal beside the Lehigh River and drowned. The situation was such that diving was a definite hazard. Payoff was guaranteed to be very low since there was no doubt the boy was dead. Several persons were diving. One of them got trapped under the ice downstream of the hole and could not come up after his air ran out. He drowned. This is an example of a large negative payoff. As an after note, the boy's body never was recovered. Shortly after this, a thaw swelled the river, probably carrying the body out to sea. Considerable attempts were made to search the banks for fifteen miles down-stream during the thaw, and repeated dives were made near the site of the drowning after the ice cover was gone. We have, then, the life of a willing volunteer lost in a futile cause.

Always, when the situation contains any element of danger to the searchers, the commander must balance probabilities and payoffs. The decision whether to continue the search or call it off must be made logically, not in an atmosphere of emotion based on either a desire to be a "White Knight" or to please a sobbing relative.

TACTICAL CONSIDERATIONS

Search Velocity and Searcher Spacing

The question of how fast a skirmish line of searchers should move and how far apart the individual searchers should be in the line is difficult to answer. Each search is different. Terrain and targets vary. Weather can play a part as can the psychological state of the searchers. These are the very basic questions that a commander must answer, however, since he is presumably the one with the most experience and knows how the overall search strategy should be carried out. A good field commander develops some experience factors after taking part in several searches.

An attempt will be made here to construct a simple model of a skirmish line and determine optimum relationships between some of the factors. As shown in the figure on the back cover, a skirmish line consists of individuals who are looking (scanning) over a semicircular area to their front and sides while they are advancing. In a very simple model, they will scan once around the semicircle while advancing a certain distance and then start another scan. A mathematical model which attempts to maximize the amount of area covered by these searchers while eliminating blank spots (un-searched areas) between searchers, gives the following relationship:

> **If R is the effective search radius of an individual searcher – that is, the distance within which he may reasonably be expected to see the target for a given terrain – then the search is most effective if the searchers are placed a distance of 1.4 R apart, and they advance a distance of 0.7 R during one scan. (See illustration on back cover.)**

Let us see how this model compares with some practical values. Experience has shown the following. For a terrain similar to that found in Pennsylvania in the Pocono Mountains (wooded plateau) or in the woodlands near the Hawk Mountain Ranger Training Area, a reasonable value of **R** is about 7 yards if the target is considered to be a small child. Most persons accept this as very reasonable when asked to demonstrate the spacing in the actual terrain. Experience shows that a skirmish line velocity of one-mile-per-hour is reasonable for this terrain and target combination. This gives a time of about 10 seconds to scan the semicircle while advancing 5 yards. This time of 10 seconds is about twice that which is necessary to complete a single scan from right to left, and suggests that searchers are not content with a single scan, but also want time to scan back to the starting point. (Some time is also needed to watch one's footing.) A well disciplined group of searchers could probably double the speed of one mile per hour if they would deliberately limit their scan to one direction and then snap their heads back to the start-scan position again for the next bit of area. Unless, however, a group is well practiced in this seemingly un-natural technique it is probably best to live with the one-mile-per-hour rate.

As a practical note, the above figures show that a 12-man search team will, under these conditions, search a swath 110 yards wide at the rate of one-mile-per-hour. This is an area coverage rate of 1/16th square-mile-per-hour. Note that we can get an expected search team performance by estimating the effective search radius for the terrain and target. Of course, once the teams are in the field, the commander must monitor their performance and check how it compares to his model. He may, in this way, be able to improve search efficiency. For instance, if the team is moving too slowly it may be that they are conducting too thorough a search and sacrificing area coverage. In this case, they should be given definite objectives in terms of time and distance to enforce increased efficiency.

Resource Management

Although there is nothing magically mathematical about Resource Management, it definitely deserves mention in any discussion of search planning. Generally the commander has a good idea of what time is available to him for the search and the number of searchers present. The first thing he must realize is that his planning time must not take time away from the search itself. A typical lost person search may involve fifty persons directly. This means that ten minutes spent planning while his searchers are idle costs the search effort over eight man-hours. When possible, the search should be planned out before searching is possible (as in the dark hours before dawn). If this is not possible, a quick evaluation should be made and the searchers started to work in the area of highest probability. Then, while the searchers are at work, the commander can put the finishing touches on his plans.

One of the first things that must be done, of course, is to estimate the magnitude of the problem. It may be that the area is so large that it cannot possibly be searched by the teams available in the time available. The commander's first action in this case is to call for reinforcements (after getting his own searchers working).

MOVING TARGETS

In all the preceding analyses, it has been assumed that **T** is stationary. When **T** is not stationary, but moving, the picture is considerably complicated. One can no longer maintain that areas once searched will remain empty. Two factors come to our rescue to aid in planning:

1. When the searchers move much faster than the target, the effect of a moving target is minimized. This factor argues for long skirmish lines which move very quickly when a moving target is being sought.

2. Payoff considerations usually indicate that the search should be planned around a stationary target. In other words, it is often the case that if the target is moving, it is not necessary that you find him.

WHERE TO SEARCH

Shortly after the 1970 publication of the first edition of Land Search Theory, William Syrotuck published a series of booklets examining search techniques and analyzed the outcome of numerous lost-person searches. The booklets are listed below for those who wish to delve deeper:

Some Grid Search Techniques for Locating Lost Individuals in Wilderness Areas, William G. Syrotuck, 1974.

An Introduction to Land Search Probabilities and Calculations, William G. Syrotuck, 1975.

Analysis of Lost Person Behavior, William G. Syrotuck, 1976, 1977 (with editorial assistance by Jean Anne Syrotuck).

These publications were originally available from Arner Publications, Inc., (P.O. Box 307, Graves Road, Westmoreland, NY, 13497) and have influenced the doctrine used by the National Association for Search and Rescue (NASAR).

The **Analysis of Lost Person Behavior** publication should be considered a "must read". There are excellent sections on the basic fears, capabilities, and behaviors of lost persons. In addition, he made a ground-breaking statistical study of where actual lost persons were found in relation to the point where they were last seen (**PLS**). He then plotted a graph of frequency versus the distance from **PLS** and prepared graphical figures showing the areas of greatest probability. He further broke the lost persons down by categories such as children, elderly, hunters, etc. and found that each category could be represented by its own value of a median distance from the **PLS** (a distance within which 50% of the persons were found).

This median distance is a most useful concept. It is regrettable that his further interpretation of this finding has a fundamental flaw (confusing 1-dimensional radial probability with 2-dimensional area probability) that may lead one astray in applying it. Space does not allow a detailed critique here. The basic data should, however, be taken to heart. The following are the most important lessons that may be drawn from his data:

On level ground: Most persons will be found within **1 to 1-1/2 miles** from the **PLS**, with the highest **probability per unit area** centered at the **PLS**, and diminishing in a circular pattern. (For those interested in statistics, read up on the *Rayleigh distribution*).

On sloping ground: For most people the circular pattern becomes an elliptical pattern with the long axis running down hill and the center shifted down hill due to the tendency of most persons to drift with the easier traveling. For mentally disturbed or suicidal persons, the bias is uphill.

Approximately 50% of lost persons are found on roads or trails in the area. This suggests that a small, highly mobile search detachment should be given trail-running as a specific task.

EXAMPLES

Lost Girl

This example comes from the author's family life experience, and illustrates an important point. In May of 1970, our family, consisting of myself, my wife, and our two young daughters visited my wife's cousin and her family (husband, wife, and one daughter). This was the first time we had visited them at a house they had recently bought in one of the upscale suburbs of Philadelphia. The house was originally a carriage house for a large estate, and, although modest itself, it was surrounded by expensive newer houses. One of their immediate neighbors had an in-ground swimming pool.

It was a beautiful spring day, and the three girls were playing by themselves in the front yard. Our cousin's girl was mid-way in age between our two girls. Our older girl was not quite 5-years old, and our younger one was not yet 3-1/2. The adults were strolling around the front and back yards. Upon approaching the girls, we noticed that the two older children were playing together and the youngest was not to be seen. Questioning of the two remaining girls elicited the response that they did not notice the third girl's departure but indicated that she had been there recently.

The adults all realized immediately that this was potentially a very serious situation. There was a fast discussion on the subject of where to look first. The front yard was right on a residential street. Inside the house was a possibility if our girl had wanted to use the bathroom or look for food in the kitchen. Because of my work on search theory, I identified the most important first place to search. If she had decided to explore the neighbor's swimming pool, she was at ultimate risk, and if she had fallen in, it was imperative that she be found within about five minutes of falling in – that being the practical time limit in drowning before brain damage sets in.

There was an immediate search of the pool area – no body in the pool. Then we split up to check the house and the front sidewalk. The front sidewalk search paid off. She had started in one direction on the sidewalk, got confused (in the strange neighborhood) as to the direction of "home", came to the corner of the block, and had sense enough to realize she had not crossed a street and should not do so now.

Search for Elderly Man

In mid-September of 1984, a 64 year-old resident of Shenandoah PA went for his customary Sunday afternoon walk in the cemetery area on the wooded heights overlooking the town. He was a large framed man, 6'3" tall, 230 pounds, dressed for a daytime walk. He was in the early stages of Alzheimer's Disease and sometimes got confused, but was very familiar with the area, which included several cemeteries, a fenced-in TV transmitter area, a road net, and considerable wooded acreage. The tree cover was heavy, but of recent growth.

He did not return. A local search effort with cars during the night proved negative. A more complete search on Monday did not find him, but an electric company lineman, who knew him but did not know he was missing, saw him about one mile west of the TV transmitter area at 3:30 during the afternoon.

On Tuesday, Fire-Rescue groups continued searching, and a State Police helicopter joined in – all to no avail. CAP aid was requested by the county SAR squad at 3:10 Tuesday afternoon. Tuesday evening an all-out search was mobilized for the next day.

In the 7-7:30 a.m. period on Wednesday morning, a large portion of what was to become a roughly 175 person CAP contingent including Ranger Teams from the eastern third of Pennsylvania assembled at police headquarters in Shenandoah and convoyed to the TV transmitter area which became our base of operations. The lineman's Monday sighting was treated as the **PLS**, and a grid search was started to cover the area within about one mile from that point.

During the morning, a half-team was given the task of checking the woods immediately outside the perimeter of the TV transmitter and the cemeteries. The only result of this search was a "Find!" of a human bowel movement with a paper towel used as toilet paper. Since there were no bathroom facilities in the area this was written off as probably from one of the searchers, even though our training stresses burying human waste.

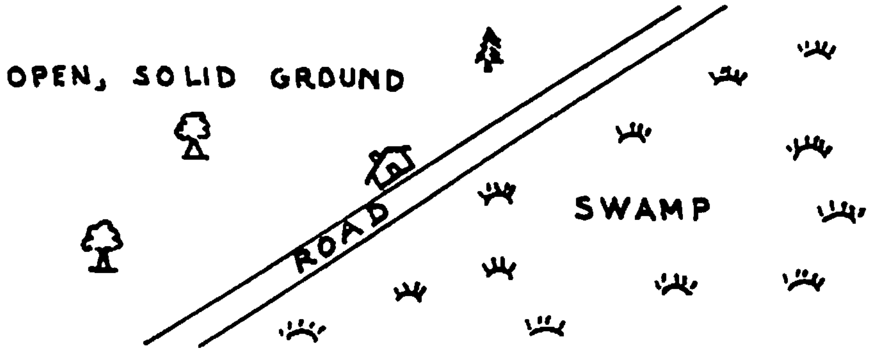
While the search continued through the afternoon, information was developed from the victim's family members to the effect that the victim always took a folded paper towel with him for emergency toilet paper, and that it was always a "Bounty" towel with a figured design. At this point the earlier "Find" was reevaluated. A return to the vicinity of the site showed that the towel had a figured design, and a search of all the paper towel supplies at the base found only plain white towels. The freshness of the "Find" suggested a recent origin, and it was decided to make this the new **PLS**. Plans were laid to gather all the returning troops and make one last search in the area immediately to the west of the TV transmitter using one long search line. At 1640 hours, a 97-man skirmish line stretching north to south was started on a one-mile search to the west, with some observers stationed on the road net at the western end. At 1715 hours, two CAP cadets encountered the victim lying semi-conscious on the ground in the woods near the TV transmitter. The paramedics took over the recovery and evacuation. It is generally considered that the victim would not have survived another night of exposure.

This search serves as a useful lesson in the importance of the **PLS** concept as well as the importance of the CAP training in reporting ***any*** unnatural item encountered as a possible clue.

Lost Boy

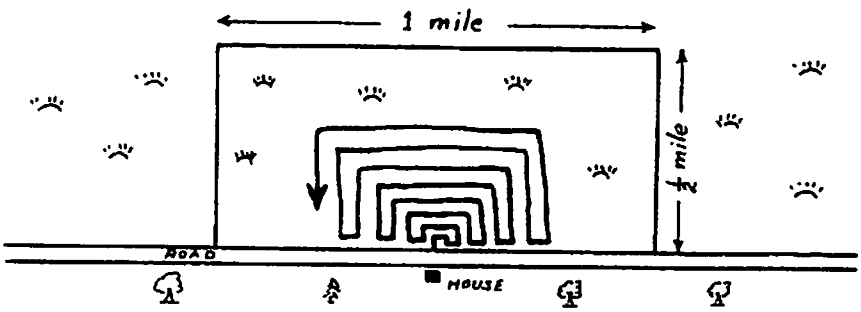
For this example, we will examine a model constructed on the basic data contained in the article referenced on the inside front cover. A three-year-old boy wandered away from his home (**PLS**) at dusk in October. He was found about midnight of the next day. He died about 3 p.m. on the day after he disappeared; trapped in a swamp. His distance from home was given as one-half mile.

To illustrate how this problem might be handled, we will make some basic assumptions about the terrain. (See drawing.) It will be assumed that the home is on a road. The ground on one side of the road is assumed to be open and solid. The ground on the other side of the road is assumed to be swampy.



The search commander has one 12-man search team at his disposal. The swampy terrain is assumed to have about the same density of vegetation as the area referenced earlier near Hawk Mountain. Therefore a 10-yard interval and one-mile-per-hour progress will be assumed. The commander makes the basic decision that he will completely ignore the "safe" side of the road on the basis that only if the child is in the dangerous territory will the search produce a high payoff – i.e., if the child is in the open country, his life is not in immediate danger and the probability is high that he will be found by some of the inevitable neighbors and other volunteers keeping a lookout for the boy. If, on the other hand, the child is in the swamp, it is necessary to find him quickly since a three-year-old boy is likely to be unable to cope with a swamp. Note that this plan is made during the night while the team is assembling at the search area so that the search can start at first light.

Since this particular team is well trained in navigation, the commander decides on a modified type of expanding spiral search (see drawing). This search starts at the house and works outward in all directions on the swamp side of the road. The basic pattern is made rectangular for simpler navigation (straight lines being much easier to figure and follow than curved ones), and the rectangle is twice as long as it is wide to maximize efficiency.



Since we, who have read the article, know that the child is trapped one-half mile from his house, the search will be successful when the team has searched a rectangle whose dimensions are one-half mile wide by one mile long, or an area of one-half square mile. At a rate of 1/16th square-mile-per-hour, this will take 8 hours. Thus, if the team starts their search at dawn (about 7a.m.) they will have found the boy by the time 3 p.m. comes around.

This is a spectacularly different ending to the story than that which actually occurred. I want to stress that the author has never been in Greenwich, nor read any more detailed account of the search, and does not have direct knowledge of the actual circumstances of terrain, etc., so this new ending must be regarded with caution. The important point to be made here, though, is that planning and training can produce results where sheer manpower (700 volunteers actually searched for the boy) will fail.

Lost Hunter

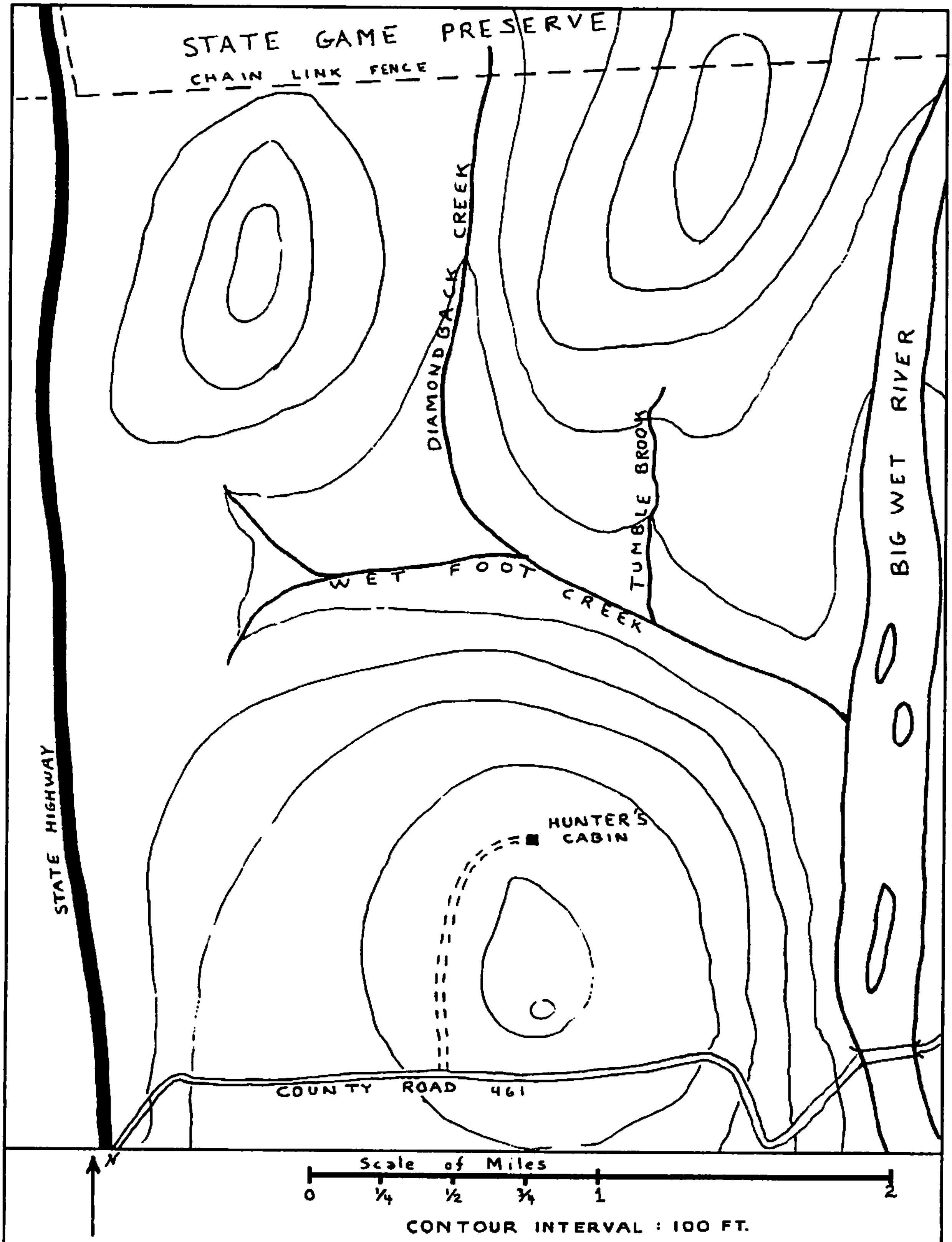
The following search problem will be presented, but no "school solution" will be given. The map and data are given here so that this problem can be used in classroom discussion. Refer to the map on the opposite page. Each person is urged to plan exactly what his or her actions would be as the commander in this search scenario.

The time is about one hour before dawn on a Saturday morning in December. You are the commander with three 12-man Ranger Teams at your disposal. The teams are reasonably well trained, but are made up mostly of teenage cadets who are due back in school on Monday. Arrangements can be made with the school authorities to keep them out longer if necessary. Each team has a vehicle and driver. The teams have walkie talkies with them with a range of about one-half mile in timber (further if high ground is available). Each vehicle is equipped with a more powerful radio on the same frequency as the walkie talkies. You have your personal vehicle (4x4) with a vehicle radio and walkie talkie.

Yesterday, J. Shootwell and his hunting companion, D. Stalker, started from the cabin (belonging to D. Stalker) to hunt deer. They started out shortly before dawn and went their separate ways. J. Shootwell announced that he was going to hunt in the general area of the hill shown in the northwest quarter of the map. Both hunters were to return for supper at the cabin at about dusk. Each man carried a cold lunch, and both were properly dressed for hunting. J. Shootwell did not return that night. He has hunted in this area for several years and knows the terrain. He would not cross the roads that bound the south and west sides, and cannot cross the chain link fence on the north or the river on the east. Therefore he is almost certainly within the area shown on the map. He is a stable type of character, 43 years old, and in good general health. While not an expert outdoorsman, he has hunted enough that he is generally at home in the woods. He habitually smokes a pipe and would have it with him.

The weather is in the high thirties during the day, dipping to about 20°F at night. There is no snow on the ground. D. Stalker is present with you at his cabin. He states that, while he heard several shots during the day, he does not think that any of them were on this patch of land. The terrain is generally similar to that already described as being in the neighborhood of Hawk Mountain. It is generally rocky, with good tree cover and medium underbrush.

What will your actions be as a search commander?



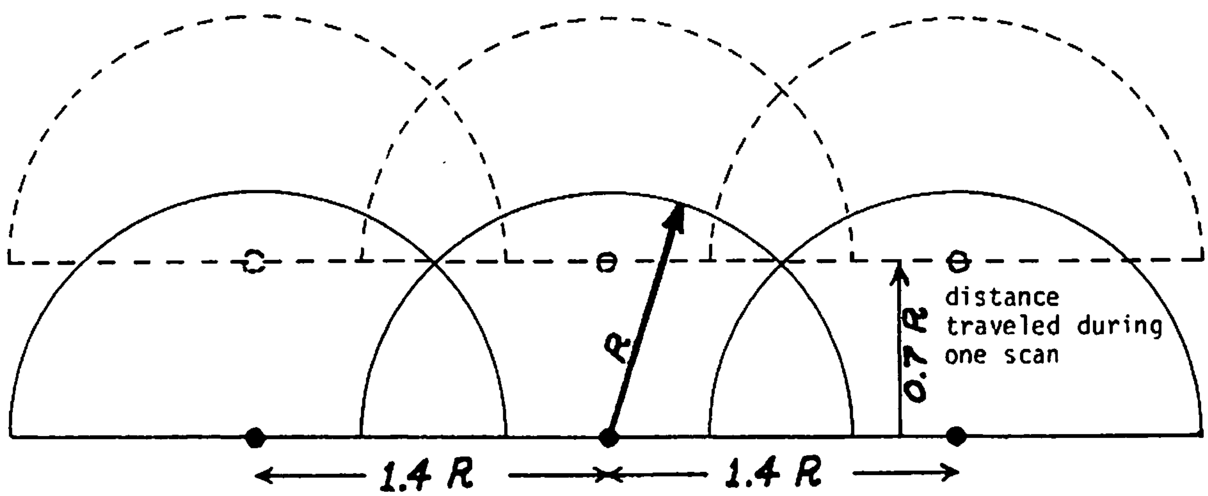
Map for Lost Hunter Problem

Table 1 – Probability of Success for Repeated Searches

n = total number of searches of the same area (all at the same **POD**).
P(1) = **POD** for one search, **P(n)** = **POD** for **n** searches.

Caution: This is a table of **POD** values. Do not use it to obtain **POS** values directly.
First find **P(n)**, then multiply by **POA** to obtain **POS**.

n	P(n)									
1	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.00
2	.19	.36	.51	.64	.75	.84	.91	.96	.99	
3	.27	.48	.66	.78	.87	.94	.97	.99		



Mathematical Model of Skirmish Line Giving Optimum Coverage During Search

Some Guidelines for Planning Searches

For areas of uniform probability – search the entire area first before re-searching a portion of the area.

For areas of non-uniform probability – search the area of highest probability first. If this proves unsuccessful, evaluate the effectiveness of your search and consult the graph on multi-square problems to make a decision on re-searching the high-probability area or going to a new area.

Evaluate the condition of the search target and the nature of the terrain and weather. Plan the search to yield a high payoff in terms of benefit to the search target.

Evaluate the total extent of the search operation and the capabilities of your resources. Call for additional help as soon as possible.

Avoid hazardous situations that may lead to high negative payoff in terms of injury to the searchers unless this is balanced by a high probability of a high positive payoff in terms of life-saving of the target.

Civil Air Patrol
Hawk Mountain Ranger School History

In response to the need for ground support for air search missions, the concept of the Ranger Team was born under the leadership of Col. Phillip Neuweiler, PAWG Commander from the late 1940's to 1970. In 1953 USAF Pararescue and survival instructors trained PAWG SAR teams at Westover AFB, Massachusetts. Due to the dedication, motivation, and high quality of the students, the instructors called them Rangers.

In 1956 the school was moved to Col Neuweiler's property at Hawk Mountain, and was staffed by USAF and CAP members. In the early 1960's Ranger Staff Cadet Training was implemented, and the Hawk Mountain Ranger School gained national prominence.

In the 1960's different Ranger Proficiency grades were established to recognize skill and experience, devised in a similar way to awards for the Boy Scouts of America. In that time, several Ranger Teams had individuals that parachuted into aircraft crash areas. There was an Airborne Ranger shoulder insignia (shown below) worn in place of the PAWG shoulder insignia.

In 1974 Brigadier General Leslie Westberg, USAF, the National Commander, attended the Hawk Mountain Ranger School. He completed requirements for, and was awarded, the Ranger First Class Proficiency Grade. General Westberg tasked National Headquarters staff to document emergency services training and to recognize and link together various related schools across the United States. Through the 1970's there were National Ranger Schools held at Hawk Mountain, the Everglades in Florida, and Black River Mississippi. Col. Bartolo Ortiz had developed Ranger Schools in Puerto Rico. Officially designated National Emergency Assistance Training (NEAT) schools, attendees of these schools wore a special insignia on the left breast pocket. The Washington Wing Challenger School was also qualified as a NEAT school, and several of their staff trained at Hawk Mountain Ranger School.

In the early 1980's the Airborne Ranger shoulder insignia was replaced with a Search and Rescue insignia. In the late 1980's, when the Air Force made the transition from the green utility uniform to the Battle Dress Uniform (BDU), which was subsequently adopted by CAP, search effectiveness was compromised. The traditional orange hat and colorful Ranger insignia became more practical, rather than ornamental.

In July 1996, Brig. General Richard Anderson, CAP National Commander, visited the Hawk Mountain Ranger School and recognized its lasting contributions naming it "the Harvard school of Search & Rescue."

To this day, in the National Search and Rescue Manual, Air Force pararescuemen are first considered for supervision of ground search teams. This text also reads,

> *"Specialized teams such as Army, Navy, and Air Force explosive ordinance (EOD) teams, Navy sea-air-land (SEAL) teams, or CAP Ranger teams should be considered next."*

The Hawk Mountain Ranger School and the Pennsylvania Wing Ranger Program has been the model for many of the search and rescue programs throughout the country. It continues to be the single longest running school of its kind, devoted to search and rescue instruction.

On September 11, 2004, The Hawk Mountain Ranger School training area was dedicated as the "*Col Phillip Neuweiler Training Center,*" and now includes eight newly constructed offices, a student shower facility and a waste water collection system.

Currently planned for future construction is a rope training tower. This tower will enable on-site instruction in high angle rescue. Currently there are plans to rebuild the chapel structure, and construct a memorial garden to honor departed staff members.

The Hawk Mountain Ranger School facility is the property of Civil Air Patrol and belongs to all members. Ranger Staff are the individuals responsible for the maintenance.

This book can be purchased through PA Wing Civil Air Patrol, Building 3-108 Fort Indiantown Gap, Annville, PA 17003; ordering information can be found at http://pawg.cap.gov/hawk/hawkbx.htm.