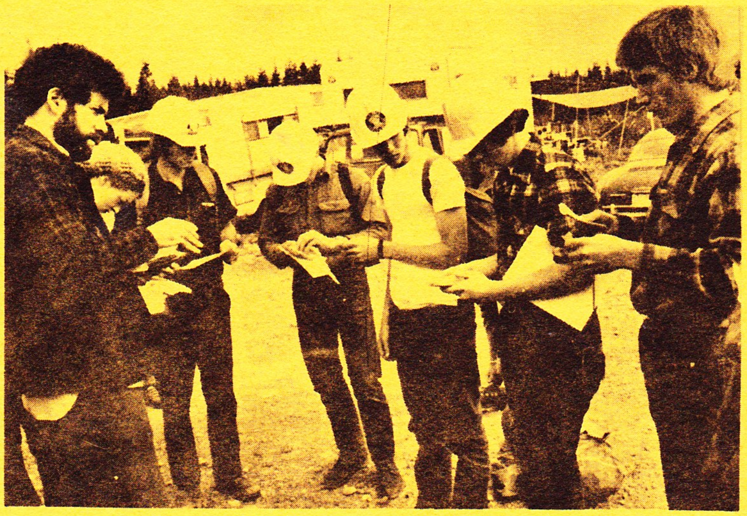
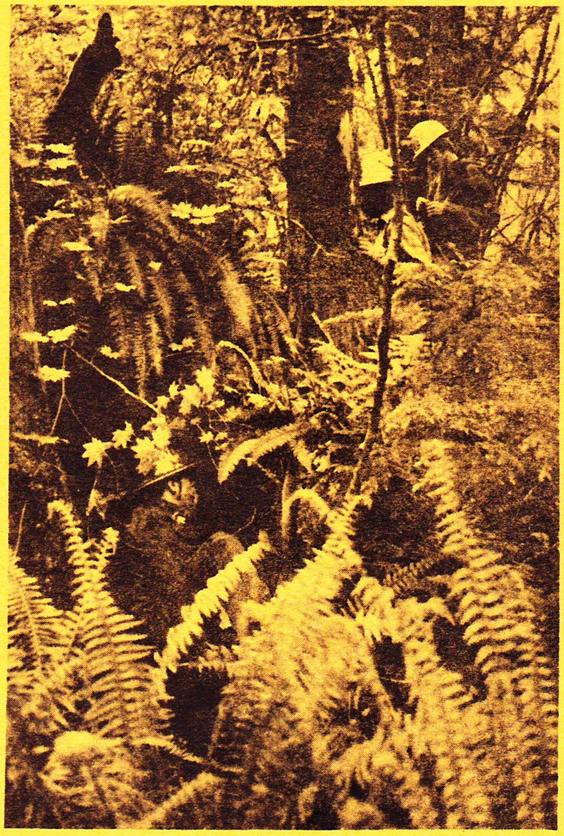
WESTERN REGION
EXPLORER SEARCH & RESCUE

AN EXPERIMENTAL ANALYSIS OF GRID SWEEP SEARCHING

March 1974





Conducted by: Seattle Explorer Search & Rescue
Printed by: Chief Seattle Council, BSA

WESTERN REGION
EXPLORER SEARCH & RESCUE

AN EXPERIMENTAL ANALYSIS OF GRID SWEEP SEARCHING

March 1974

Conducted by: Seattle Explorer Search & Rescue

Written by: Jon Wartes

Western Region ESAR
790 Lucerne Drive, Sunnyvale, California 94086

Contents

AN EXPERIMENTAL ANALYSIS OF GRID SWEEP SEARCHING

Summary

A field experiment was conducted to test the thoroughness and efficiency of three grid sweep spacings under conditions of thick ground cover. Thoroughness was defined as the % of items recovered. Efficiency was defined as the proportion of items recovered per man-hour of search effort. The sampling included 60,000 ft. of gridding by six-man ESAR teams by day and night. 45 human subjects (conscious and unconscious) and 200 ½ pt. milk cartons were used as "finds."

As predicted, grid methods using small between-man spacings were most thorough but large spacings were most efficient (daytime.) With one exception, all grid methods were more effective by day than night. Of the three types of finds, conscious subjects were the easiest to find, unconscious subjects next easiest, and ½ pt. milk cartons were the hardest. During the daytime, it was found that teams tended to pick up speed, thoroughness remained the same in spite of the speed increase, and that, as a consequence, efficiency increased. Questions asked of the human subjects suggested that thoroughness can be increased if team members are taught to look behind themselves as well as ahead.

Sections are included on (1) Probability of Detection (POD) and the use of POD tables for multiple sweeps of the same area, (2) a theoretical discussion on the "most efficient" search method, (3) implications of this research for night searching and search tactics, and (4) decision making.

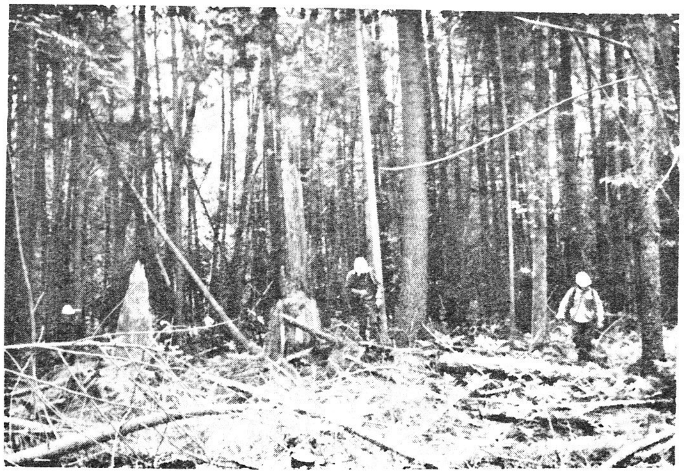
Introduction

As a search method, gridding has generally been regarded as thorough but extremely slow. The man-power requirements to search even a small area of thick ground-cover can be enormous. Sweep searches of many square miles become virtually impossible when the availability of manpower and speed of the search are considered.

Until recently we tended to accept gridding as a slow search method and to approach the problem through the training of larger numbers of searchers. We've learned how to run search operations involving hundreds of people and many SAR units. But for a long time the basic principle of gridding "so that you can be sure the lost person isn't in the searched area" remained dominant. The usual approach was to thoroughly search a portion of the suspected area until (1) all available man-power was used up, or (2) the lost person could no longer be alive. Emphasis was, therefore, placed upon the proper choice of the most likely areas where the lost person might have gone; these areas were searched first. Often, however, there were no especially likely areas or once the priority areas were covered, no clear indication emerged as to what area to search next. With emphasis upon thoroughness, portions of the remaining area were searched and other portions were not. The operation leader might base his choice upon a hunch or a guess.

A few years ago, something curious began to happen. A number of instances took place where friends or relatives of the lost person, while just wandering around within the search area, found the lost person. The phrase "finding him just ahead of one of our teams" kept coming up. At first it was regarded as fortunate coincidence. But when it happened several times it began to soak in that there was a message there. If untrained searchers using what amounted to unsystematic and non-thorough methods could produce better results than a larger number of trained searchers who devoted more time to the search, then the effectiveness of the method has to be questioned.

From this thinking evolved the idea that the criteria for measuring search effectiveness should involve more than just thoroughness. That another criteria, one that relates results to the time required to achieve those results, should be developed. A very fast search method which covers 1 sq. mi. with 50% thoroughness would, in this context, be seen as more effective than a slow method which covers 1/5 sq. mi. with 100% thoroughness. In the long run the first method will produce more results or will produce the same results in less time. In this paper, we will call this criteria "efficiency."



In theory, it was felt that very fast sweep methods would be less thorough than slower ones but that thoroughness would not drop by the same factor as the increase in speed. (If method A is five times faster than method B, it will be maybe 1/2 as thorough rather than 1/5 as thorough.)

Others have at least subjectively considered the same question. W.G. May(1) described a "loose line" search pattern which is essentially a play-off between speed and thoroughness.

Until this point, however, it has been only a theory supported by intuition. The key question was "do fast sweep methods (characterized by larger between-man distances) produce more per unit of time despite the decrease in thoroughness"(or, in other words, does the advantage of speed more than compensate for the loss of thoroughness?)

In May of 1972, Seattle ESAR conducted an experiment to measure both thoroughness and efficiency of several grid methods. Several errors were made in conducting the experiment; most of the results were subject to question. With lessons learned on how to manage a project of this scope, a more elaborate experiment was conducted on June 2 & 3, 1973. It is this experiment reported here.

Definitions

<u>THOROUGHNESS</u>: The ratio of the items found to the number of items in the team's path.

Thoroughness = $\frac{A}{B}$ Where A = No. items found
B = No. items in the team's path.

NOTE: This definition allows thoroughness to exceed 100%. If a team finds 9 out of 10 items from within its path plus another 2 items off to the side of its path, its thoroughness will be 11/10 or 110%.

This definition was selected because:

1. On real searches, a find would not be discarded just because it was found to the side of a grid team.
2. To disregard items found to the side of the team would be to distort the actual performance of the team. Since grid methods can only be changed or improved by modifying what happens at the team level, the most sensitive measure aimed at the team level is the most desirable.

CAUTION: This means that Thoroughness is not quite the same as the "Probability of Detection (POD) defined in the National SAR Manual(6) or in Bill Syrotuck's recent report(3).

A conversion has been worked out (see section on Probability of Detection) where the thoroughness data obtained here is equated to POD values.

<u>EFFICIENCY</u>: The proportion of items found within a unit area per man-hour of search time.

Efficiency = $\frac{AD}{BC}$ Where: A = No items found.
B = No. items in the team's path.
C = No. of man-hours of search time.
D = Size of area searched.

This definition came out of the reasoning that results achieved by teams(A) could only be meaningful if they were compared to potential results(B). Man-hours (C) is a good measure of effort expended to produce results but man-hours can be meaningfully compared only if area size (D) is equated.

As to the interplay of the variables within the formula, it was subjectively agreed that Efficiency should behave as follows:

1. If method M covers twice the area as method N (everything else constant), it should be twice as efficient.
2. If method R produces the same results as method T in half the time, it is twice as efficient.
3. If the team finds a higher proportion of items within the same amount of time (other variables constant), it should be more efficient.

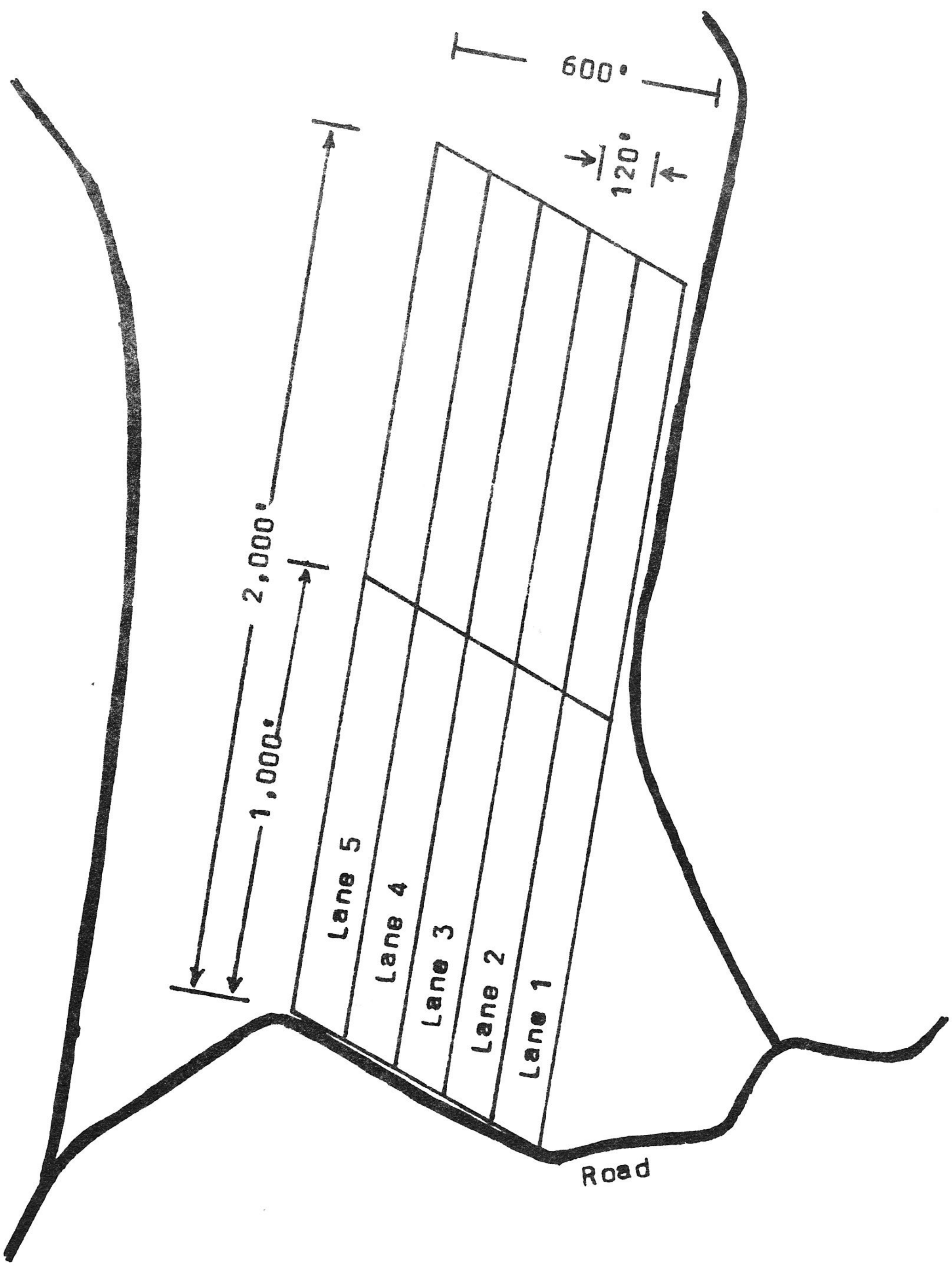
Etc.

The above definition was adopted because it reflects this behavior.

Unlike thoroughness, an index of the efficiency of a grid method has little meaning by itself. A thoroughness of 75% can be understood, but what does an efficiency of .090 mean? Efficiency ratings are useful only when two or more numbers are compared. If a 20' grid spacing produces an efficiency index of .043 and a 100' spacing yields an efficiency of .104, then the 100' spacing can be said to be more efficient. Efficiency by itself has no meaning; it is useful only when comparing two or more methods to each other.

The Test Area

The experiment was conducted within a 600 X 2,000 ft. test area located 4 miles North of the town of Snoqualmie, Washington. The area was marked by six parallel string lines forming 5 separate lanes. The ground cover consisted of medium-to-extremely heavy underbrush under a canopy of 80' to 100' conifers; This area is fairly typical of Western Washington.

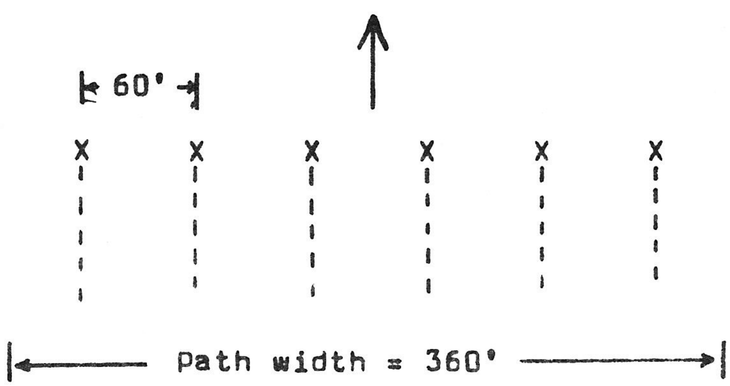


Search Methods

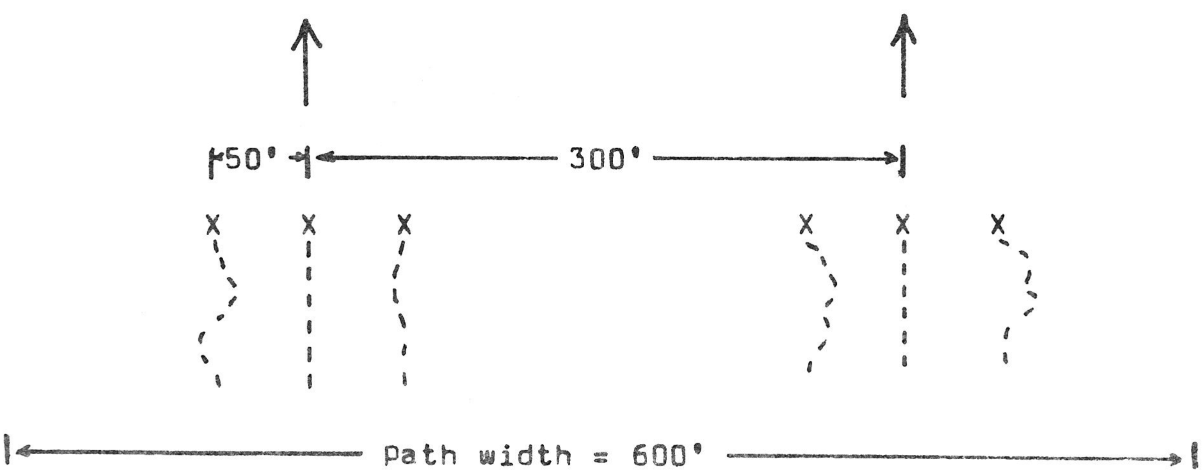
Three grid methods were used - they differ primarily in the between-man spacing.

METHOD #1: Average 20' between-man distance.

METHOD #2: Average 60' between-man distance.



METHOD #3: Average 100' between-man distance.



Subjects

Three kinds of "finds" were placed within the test area.

1. Qty: 200   ½ Pt. Milk cartons, brown & white in color.

   Half were placed such that they could be seen in 180° of arc at a distance of 20'.

   Half were placed such that they could not be seen in any direction at a distance of 10'.

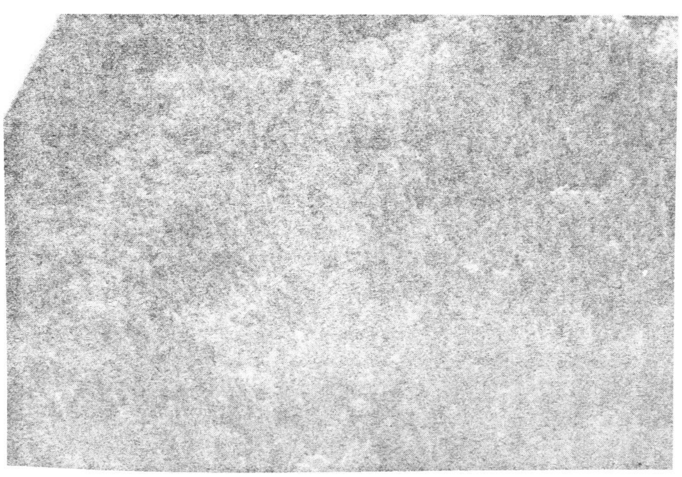
2. Qty: 23   Unconscious Persons

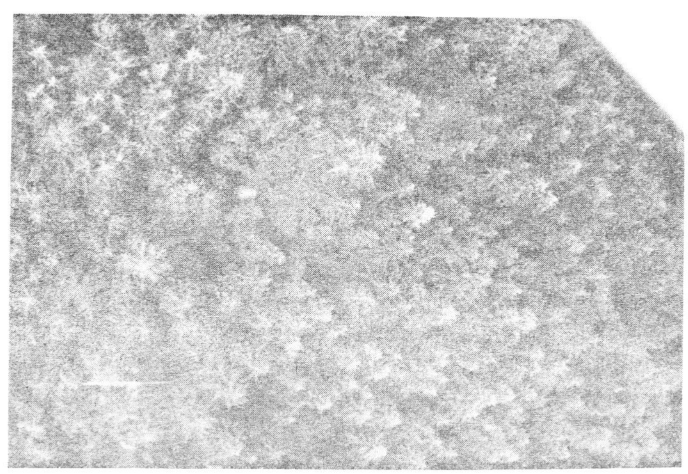
   The instructions given were "motionless and silent. Not to hide but seek any shelter or comfort that a lost person might make use of prior to becoming unconscious."

3. Qty: 22   Conscious Persons

   The instructions given were "Down and unable to move but able to respond vocally as a team approaches. When a team approaches close enough that you can see or hear it, call out to the team. Use a voice volume that you would normally use if you were carrying on a conversation with a person 20' away. Use any other actions that might attract the team but remain down in one position."

Both categories of persons were recruited from families & friends of SAR members and several outdoor recreation groups in Seattle. All were teen-agers or adults.





Searchers

The search sweeps were carried out by 6 6-man teams; all are members of Seattle Explorer Search & Rescue.

Lighting Conditions

Daytime: Bright Sunlight

Night: Approximately 80% of the searchers used flashlights (hand-held or headlamp.) The remainder used gas lanterns of several kinds.

Statistical Test

Analysis of Variance

Confidence Level

.05 Level

Two averages are said to be significantly different if there is a less than 5% chance that they are not different. Similarily, two numbers are said to be significantly the same if there is a less than 5% chance that they are not the same. Comparisons not falling into either category will be listed as inconclusive.

Method

The size of the search area was planned such that a 6-man team spread apart at a 20' interval would fill one lane. Similarily at 60' between-man distance the team occupied 3 lanes; at 100' spacing, 5 lanes were used. This control was important. The lanes provided definate boundaries that are essential to knowing the potential results that could be achieved on each team sweep.

Measured starting pegs were placed along the base line to assure proper initial spacing of each team.

The first 3 sweeps by each team were carried out in the southern ½ of the test area. The 4th through 6th sweeps were done in the northern ½. Between time all subjects were moved from one half to the other. This area chance substantially reduced the experimental error of team members learning where some of the subjects were located & using this knowledge on subsequent sweeps.

On the first run, all 3 grid types were used by two teams each. On the second run, each team changed grid type but, as before, all 3 grid types were used by two teams each. This schedule was maintained throughout the daytime and night time runs. This kind of schedule tended to balance two kinds of possible error sources;

1. If team performance changed throughout the day (increased due to warm-up or decreased due to fatigue) it would be evenly distributed among all 3 grid methods.

2. If one or two teams were notably better than the others, their performance would be distributed equally among the grid types.

At the end of the 6th team run, the daytime experiment ended. All teams and subjects returned to base for dinner.

After dark, the subjects again returned to the search area (taking a different location) and 4 additional sweeps were made by each team. Only the southern ½ of the test area was used.

TOTAL SAMPLING

	Number of team sweeps (1,000' each)		
	Daytime	Night time	Total
20' Grid	12	8	20
60' Grid	12	8	20
100' Grid	12	8	20
Total	36	24	60

RESULTS
COMPARISONS OF GRID TYPES

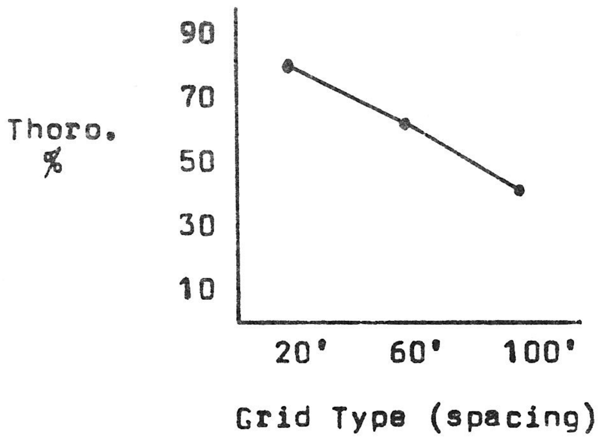
	DAY TIME Grid Type (Between-man distance) 20'	60'	100'	Ave. for 3 grid types	NIGHT TIME Grid Type (Between-man distance) 20'	60'	100'	Ave. for 3 grid types
AVE. THOROUGHNESS (%) (Definition #1)								
Milk Cartons	42.2	25.6	15.6	27.8	40.0	17.5	10.5	22.7
Unconscious Subjects	105.7	71.4	50.7	76.0	79.3	38.3	19.0	45.6
Conscious Subjects	94.2	94.7	56.5	81.8	121.8	70.2	50.0	80.7
Average of Above	80.7	63.9	40.9	61.9	80.4	42.0	26.5	49.7
AVE. EFFICIENCY								
Milk Cartons	.020	.028	.029	.025	.012	.014	.013	.013
Unconscious Subjects	.049	.077	.095	.074	.026	.030	.025	.027
Conscious Subjects	.043	.100	.104	.082	.039	.055	.064	.053
Average of Above	.037	.068	.076	.060	.026	.033	.034	.031
TIME Ave. Min. per Sweep (1,000')	25.3	30.1	29.3	28.2	33.6	38.3	40.1	37.3

Significantly different — Significantly Same — Inconclusive

Results: Comparisons of Grid Types

Below are charts showing the averages for the 3 grid methods. See the facing page for a break-down according to the type of find.

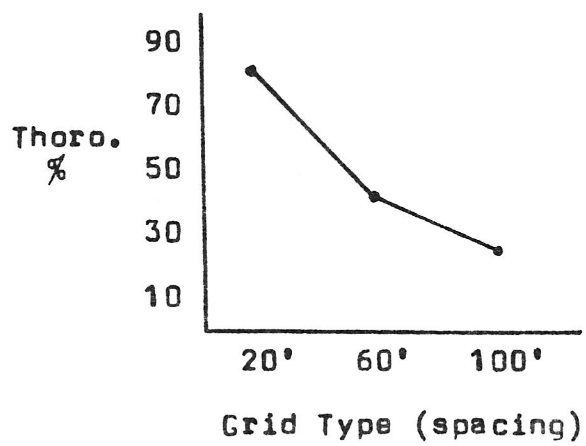
AVERAGE DAYTIME THOROUGHNESS



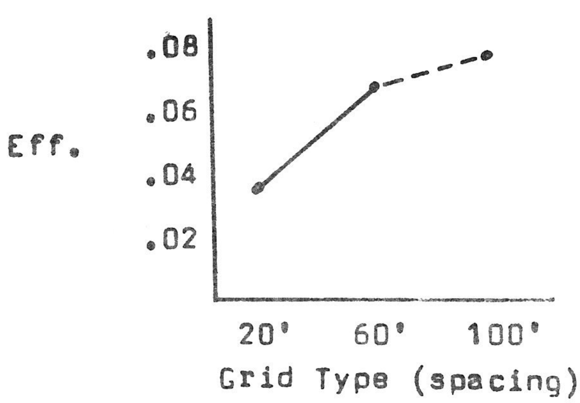
1.1 Thoroughness decreased as between-man spacing increased.

AVERAGE NIGHT TIME THOROUGHNESS

1.2 Thoroughness decreased as between-man spacing increased.



AVERAGE DAYTIME EFFICIENCY

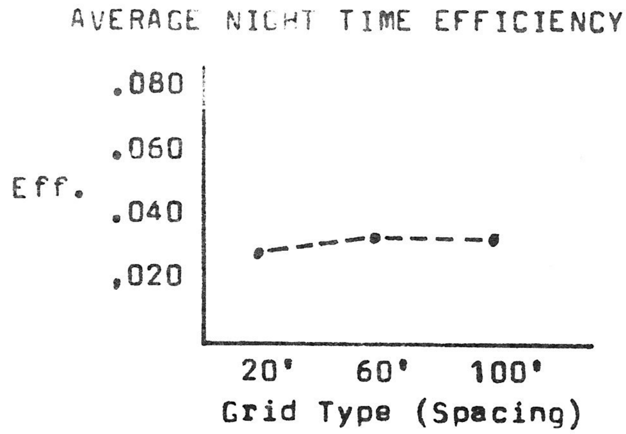


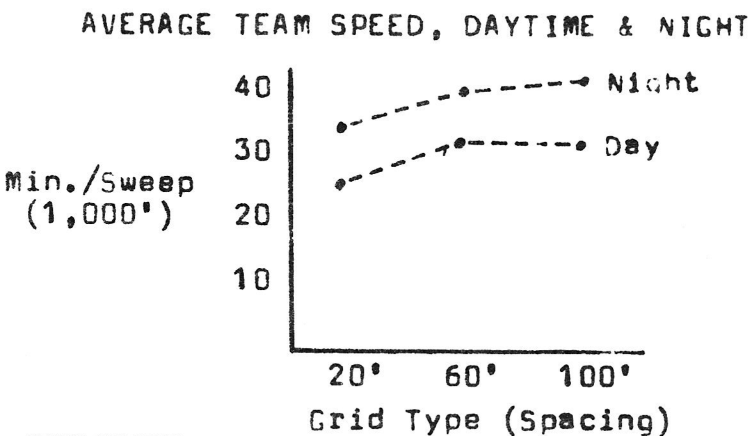
1.3 The 60' and 100' grid types were both more efficient than the 20'. Differences between the 60' and 100' were inconclusive.

——— Significant Difference

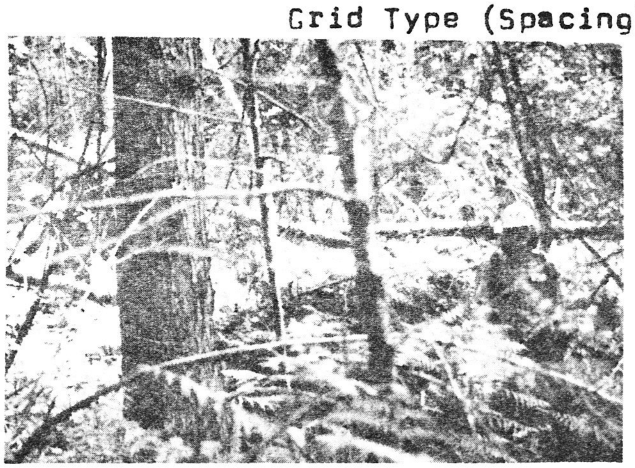
– – – – Inconclusive

1.4 Differences in the efficiencies of the 3 grid methods were inconclusive.





1.5 Differences in team speed between the 3 grid types were inconclusive.



Discussion: Comparisons of Grid Types

THOROUGHNESS

The subjective feeling that close grids are more thorough than methods using wider spacing has been confirmed by this experiment. This was especially true during the day (11/12 comparisons were significantly different. The pattern held true at night but not quite as strongly (9/12 were significantly different.)

The one interesting exception to this trend involved conscious subjects during the day; the performance of the 20' grid and 60' grid were the same. One might speculate that this was due to the subject calling out as the team approached. This observation is probably best regarded as tentative; the sample size is not large. If confirmed, this observation would be useful information to an operation leader in those situations where the subject is still felt to be conscious.

EFFICIENCY

During the daytime runs, a consistent pattern emerged that the 60' and 100' grids were more efficient than the 20' spacing. However, differences between the 60' and 100' methods were inconclusive. The concept of efficiency (non-thorough methods produce more results per man-hour of effort) was, therefore, confirmed by this experiment; the 20' spacing was consistently less efficient than the other two methods. Unfortunately the results did not reveal much about the shape of an efficiency curve; it demonstrated only that efficiency, as a construct, does exist. In this test, comparisons of grid types where the ratio of spacing was 3:1 (60' to 20') or 5:1 (100' to 20') produced consistent differences in efficiency. However, a ratio of 1.67:1 (100' to 60') was inconclusive. The question now becomes "what is the minimum ratio necessary to produce a significant difference?" Would a 2:1 or 2.5:1 ratio produce significantly different efficiencies? These questions were not answered here.

The results concerning night time efficiency were mostly inconclusive. The only exception was within the category of conscious persons where the same pattern emerged as during the day. Efficiency as a criteria at night is, therefore, still subject to debate.

The difference between daytime and night time results suggest two questions:

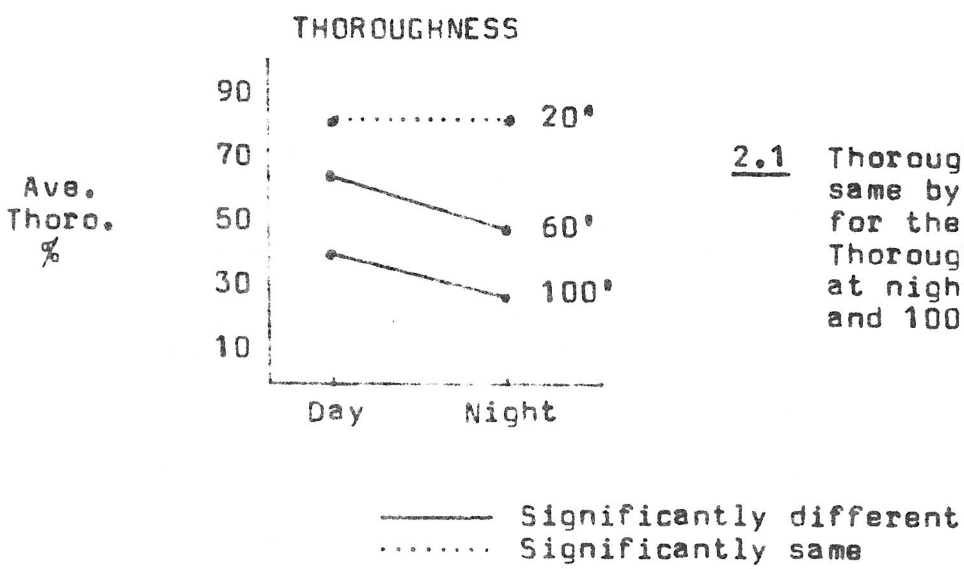
1. Are any spacings at night systematically more efficient than others?

2. If so, is a different ratio in the spacing of methods in order to produce significantly different results required at night as opposed to the day? (If a 3:1 (60° to 20°) produces a difference during the day, would a 7:1 (140° to 20°) be necessary in order to get different results at night?)

Neither of the answers are given from this experiment.

Results: Day – Night Comparisons

A break-down of the data appears on the next page. The major conclusions are described below.

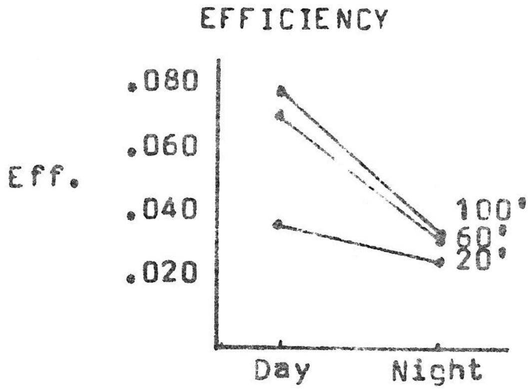


2.1 Thoroughness was the same by day or night for the 20° grid. Thoroughness decreased at night for the 60° and 100° grid methods.

RESULTS
DAY-NIGHT COMPARISONS

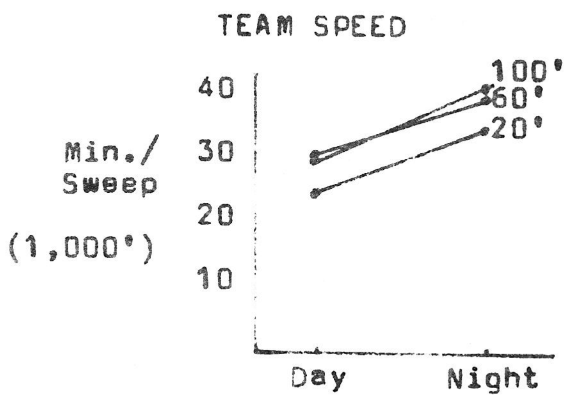
	DAY TIME Grid Type (Between-man distance)				NIGHT TIME Grid Type (Between-man distance)			
	20'	60'	100'	Ave. for 3 grid types	20'	60'	100'	Ave. for 3 grid types
AVE. THOROUGHNESS (%) (Definition #1)								
Milk Cartons	42.2	25.6	15.6	27.8	40.0	17.5	10.5	22.7
Unconscious Subjects	105.7	71.4	50.7	76.0	79.3	38.3	19.0	45.6
Conscious Subjects	94.2	94.7	56.5	81.8	121.8	70.2	50.0	80.7
Average of Above	80.7	63.9	40.9	61.9	80.4	42.0	26.5	49.7
AVE. EFFICIENCY								
Milk Cartons	.020	.028	.029	.025	.012	.014	.013	.013
Unconscious Subjects	.049	.077	.095	.074	.026	.030	.025	.027
Conscious Subjects	.043	.100	.104	.082	.039	.055	.064	.053
Average of Above	.037	.068	.076	.060	.026	.033	.034	.031
TIME								
Ave. Min. per Sweep (1,000')	25.3	30.1	29.3	28.2	33.6	38.3	40.1	37.3

Significantly different   Significantly Same   Inconclusive



2.2 Efficiency was lower at night than during the day for all types of grid methods.

2.3 Team speed was slower at night than during the day.



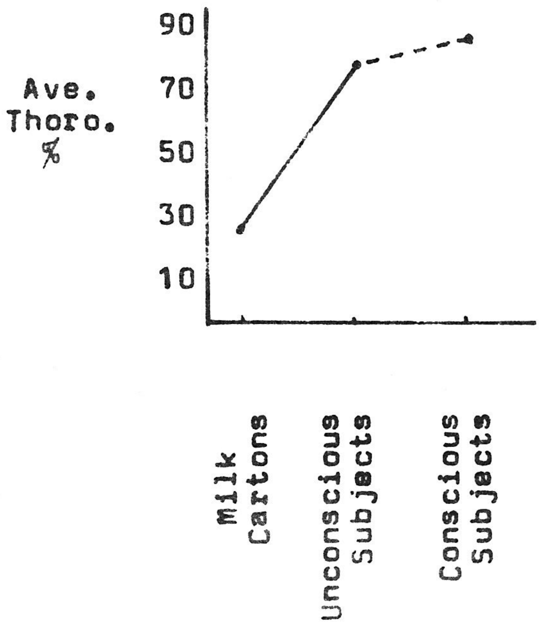
Discussion: Day-Night Comparisons

Uniformly the results showed that night searches are less thorough, less efficient, and slower than day searches. The only exception related to thoroughness using a 20' spacing: day & night performance was the same. This result might best be taken with caution; it was derived from 3 sub-categories (milk cartons, unconscious subjects, conscious subjects) all of which produced inconclusive day-night comparisons individually.

Results: Comparisons of Type of Find

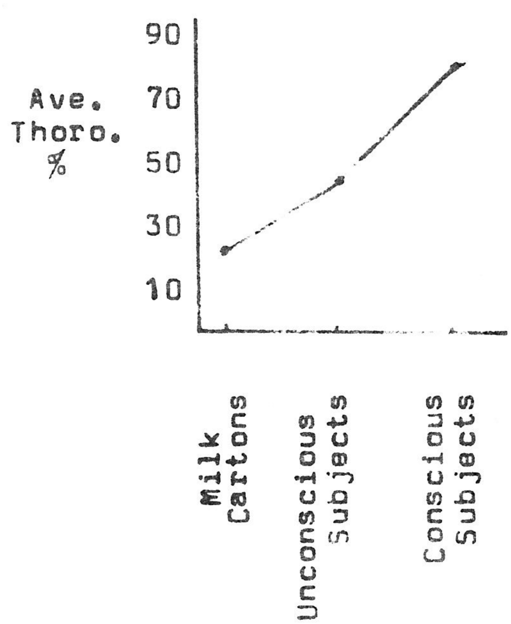
Below are charts showing averages for the 3 kinds of "finds." The next page shows the break-down according to grid method.

AVERAGE DAYTIME THOROUGHNESS



3.1 Search thoroughness was greater for persons than for milk cartons. Differences between the kinds of subjects were inconclusive.

AVERAGE NIGHT TIME THOROUGHNESS



3.2 Thoroughness was highest for conscious persons, next highest for unconscious persons, & lowest for milk cartons.

——— Significant Difference

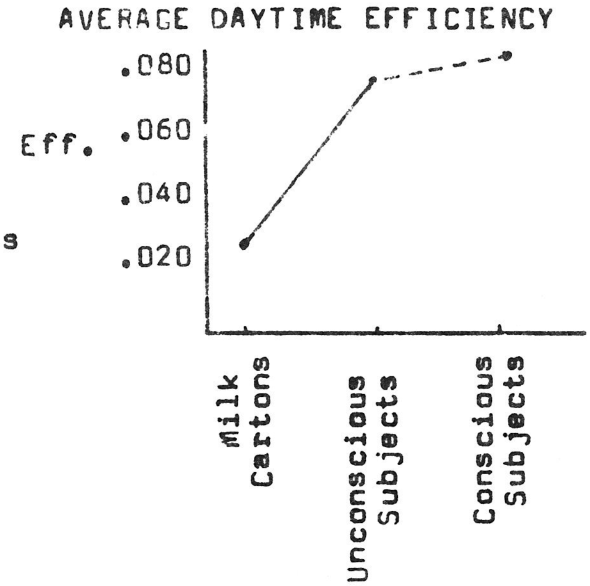
------ Inconclusive

RESULTS
COMPARISONS OF TYPE OF FIND

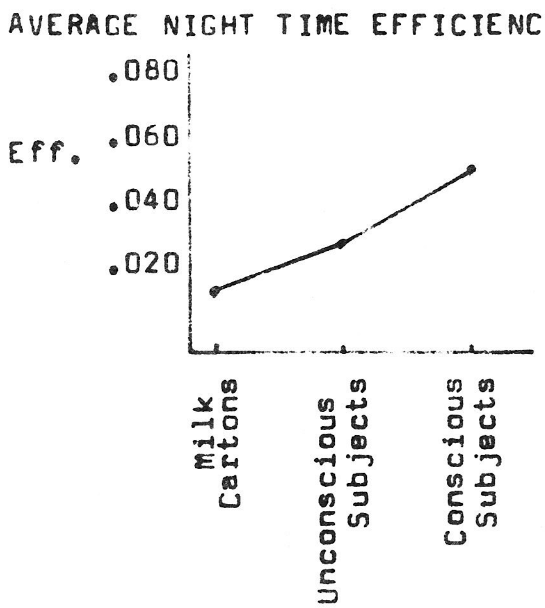
	DAY TIME				NIGHT TIME			
	Grid Type (Between-man distance)				Grid Type (Between-man distance)			
	20'	60'	100'	Ave. for 3 grid types	20'	60'	100'	Ave. for 3 grid types
AVE. THOROUGHNESS (%) (Definition #1)								
Milk Cartons	42.2	25.6	15.6	27.8	40.0	17.5	10.5	22.7
Unconscious Subjects	105.7	71.4	50.7	76.0	79.3	38.3	19.0	45.6
Conscious Subjects	94.2	94.7	56.5	81.8	121.8	70.2	50.0	80.7
Average of Above	80.7	63.9	40.9	61.9	80.4	42.0	26.5	49.7
AVE. EFFICIENCY								
Milk Cartons	.020	.028	.029	.025	.012	.014	.013	.013
Unconscious Subjects	.049	.077	.095	.074	.026	.030	.025	.027
Conscious Subjects	.043	.100	.104	.082	.039	.055	.064	.053
Average of Above	.037	.068	.076	.060	.026	.033	.034	.031

] Compared numbers are significantly different.

⁝ Compared numbers are neither significantly different nor the same (inconclusive).



3.3 Search efficiency was greater for persons than for milk cartons. Differences between the kinds of subjects were inconclusive.



3.4 Efficiency was highest for Conscious persons, next highest for Unconscious persons, and lowest for milk cartons.

——— Significant Difference
- - - - Inconclusive

Discussion: Comparison of Type of Find

The results here were rather non-spectacular: milk cartons were the hardest to find and conscious persons were generally the easiest.

About the only interesting observation is that unconscious persons ranked below, but not far below, conscious persons during the day. At night, the gap between unconscious & conscious subjects was greater. This is probably due to the fact that the conscious person has two things going for him (can be seen or heard) where the unconscious person can only be seen.

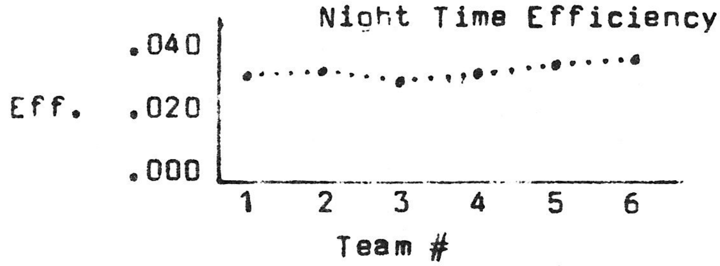
Results: Differences Between Teams

4.1 DAYTIME THOROUGHNESS: Differences between the teams were inconclusive.

4.2 NIGHT TIME THOROUGHNESS: Differences between the teams were inconclusive.

4.3 DAYTIME EFFICIENCY: Differences between the teams were inconclusive.

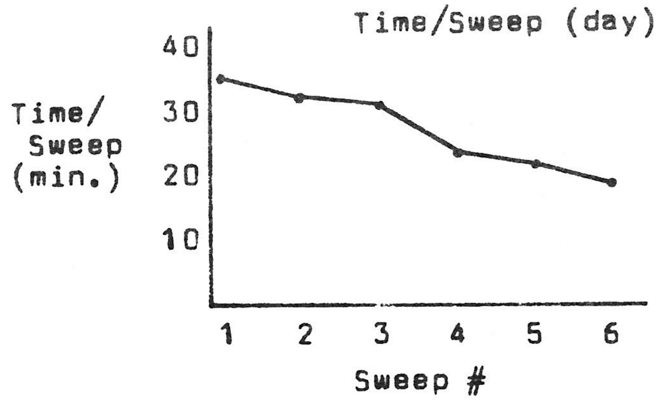
4.4 NIGHT TIME EFFICIENCY: The efficiencies of the 6 teams were the same.



Results: Time Comparisons

TIME PER SWEEP - DAY

5.1 The time required to make one sweep decreased as a function of daytime gridding practice (no. of previous sweeps that day.)



5.2 TIME PER SWEEP - NIGHT
An analysis of the time required to make one sweep as a function of night time gridding practice (no. of previous sweeps that evening) was inconclusive.

5.3 TIME DIFFERENCES BETWEEN TEAMS - DAY & NIGHT
Differences between teams in the time taken to make one sweep were inconclusive.

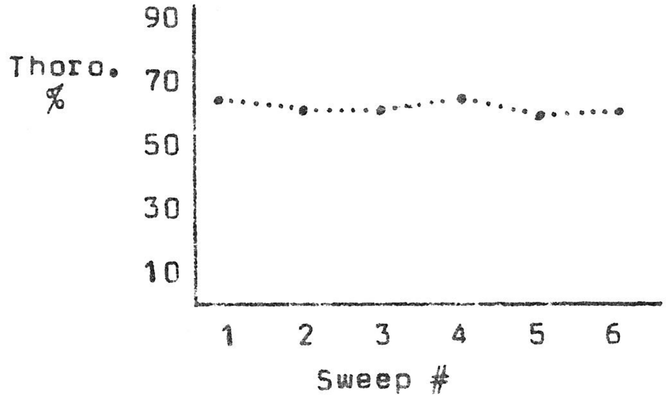
5.4 TIME DIFFERENCES BETWEEN TYPES OF GRID - DAY & NIGHT
An analysis of the time required to make one sweep as a function of grid type was inconclusive.

Discussion: Time Comparisons

The fact that the teams increased speed through the daytime runs suggests that there is some sort of "warm up" that takes place; as the team members settle into the routine of gridding, their speed increases. Logically there would be some point where fatigue sets in and speed would be expected to decrease; apparently this occurrs sometime after 6,000' of daytime gridding.

Results: Performance as a Function of Previous Practice

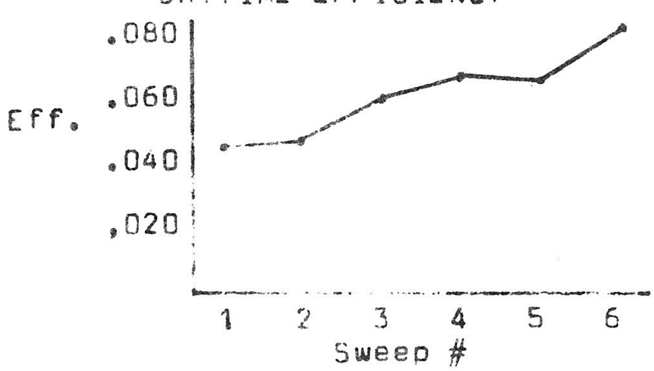
DAYTIME THOROUGHNESS



6.1 Thoroughness did not change as a result of previous day time gridding practice (no. of previous sweeps.)

6.2 NIGHT TIME THOROUGHNESS
Changes is thoroughness as a function of previous practice were inconclusive.

DAYTIME EFFICIENCY



6.3 The efficiency of the teams increased as a function of previous daytime gridding practice (no. of previous sweeps.)

6.4 NIGHT TIME EFFICIENCY
Changes in efficiency as a function of previous practice were inconclusive.

Discussion: Performance as a Function of Previous Practice

The following three daytime results are of interest when considered together:

5.1 The time/sweep decreased as a function of practice.*

6.1 Thoroughness did not change as a result of practice.*

6.3 The efficiency of the teams increased as a function of practice.*

*Practice: no. of previous sweeps that day.

Under the definition of efficiency given here, it was postulated that if speed could be increased (5.1) while thoroughness was held constant (6.1), then efficiency would increase (6.3). This is exactly what happened here. No conscious attempt was made to have the teams increase in speed: it happened spontaneously (warm-up factor mentioned earlier.)

Results: Questions Asked of Subjects

The following questions were asked of 34 of the 45 persons who acted as subjects:

7.1 Question: "Of the times when a team missed you, how close had the nearest person come?"

Results: Average: 14'
Range: 1'-50'

7.2 Question: "Of those times you were missed, what % would have found you if they had looked behind?"

Results: Average: 56%
Range: 0-100%

Discussion: Questions Asked of Subjects

The first question confirms the observation that, in the dense brush of Western Washington, its quite possible to come very close to a person and still miss him.

The other question has implications for training: gridding thoroughness will be higher if the team members are taught to look behind themselves as well as ahead.

Limitations of This Study

1. SMALL SAMPLE SIZE

This report is based upon a total of 60 1,000' sweeps by 6 6-man teams. Comparisons of specific sub-groups (e.g. daytime thoroughness of conscious subjects for the 20' grid compared to the 60' grid) should be regarded as tentative. More general conclusions which were consistently demonstrated within their sub groups will probably be sufficiently reliable (e.g. the 60' grid is more efficient than the 20' grid during the day.)

2. WEATHER & TERRAIN

This experiment was conducted in only one kind of terrain during good weather. There is no way to generalize its implications for other areas or weather conditions. Such experimentation is possible but would require massive resources to conduct.

3. THE EFFECTS ON TEAM MEMBER MORALE BY REPEATEDLY FINDING OBJECTS

In this experiment, each team member usually found several subjects and/or milk cartons during each sweep. This set up a rewarding system which usually does not exist on real searches. Most grid searches are characterized by long hours of hard work with little results. There is no way to estimate the influence of this variable.

4. UNCONSCIOUS & CONSCIOUS SUBJECTS NOT CARRYING OUT THEIR ASSIGNED ROLES

A portion of the staff frequently walked around within the test area to make sure each subject was properly acting within his assigned role. No problems were detected but is is possible that some subjects did deviate from their assignment.

5. TEAM MEMBERS FINDING THE SAME SUBJECT A 2ND TIME ON A SUBSEQUENT SWEEP.

This did happen several times but was kept to a minimum by:

1. Pre-arranging the sweeps assignments such that it was unlikely for the same person to pass the same way a 2nd time.

2. Changing the search area for the 4th, 5th, and 6th daytime sweeps.

3. Pre-arranging the type of grid such that, on the last sweep, each team was doing a different type of grid. Any error due to having learned the area on previous sweeps would be balanced by the fact that it influenced all 3 methods equally.

6. ATMOSPHERE OF A PRACTICE SEARCH

Instructions were given to the fellows to respond to this problem the same as they would to a real search. However, the atmosphere of a practice search is not the same as a real operation. The duration of rest stops between sweeps was longer than usual in order to keep the teams staggered as they went into the area. There is no way to measure the influence of this variable.

7. THE WORD "EFFICIENCY" CAN BE MISINTERPRETED

The definition of efficiency used here is quite specific and is derived from only 4 variables. However, to the average person the word connotes possibly many things. To some, search efficiency may relate to physical condition, hunger, thirst, boredom, internal motivation, weather, adequacy of equipment, ability to get along with other team members, and many many more. None of these variables have been considered here. Note one distinction however, this report attempts to deal with efficiency of search methods (based upon spacing) not searchers. This distinction is possible if one is willing to make the presumption that the above variables (physical condition, weather, etc.) would influence each grid method more or less equally (e.g. heavy rain would slow down a 20' grid and 60' grid about the same.)

Probability Of Detection

The National SAR Manual (6) defines Probability of Detection as "The probability that the search object will be detected under given conditions if it is in the search area." Having such an estimate can be very useful to an operation leader. If efficient methods (as opposed to thorough methods) are to be used, then an estimate of thoroughness must also be made; a searched area must not be represented as being searched more thoroughly than it really was.

The following chart gives the best estimate of the Probability of Detection obtainable from this experiment.

PROBABILITY OF DETECTION ESTIMATES
for several kinds of "finds" (%)

	Day			Night		
	20'	60'	100'	20'	60'	100'
½ pt. Milk Cartons	43	21	15	28	18	11
Unconscious Subjects	94	67	51	64	37	19
Conscious Subjects	89	86	56	94	68	50
Unconscious and Conscious Subjects Combined	92	71	53	81	52	35

While the above table provides the best estimates available for sweep searching, there are three major error sources in applying these results to real search operations:

Error Sources:

1. Only one kind of ground cover was sampled here; other areas will undoubtedly result in different figures.

2. Only 3 grid types were tried here. Other grid spacings or styles would produce different values.

3. Information concerning team spacing must be accurately conveyed between teams and base. In the several years since ESAR units have begun working with methods of wide spacing, we have noticed a very definite tendency for team members to want to be closer together. If

two 3-man teams are instructed to be 300' apart (center-to-center), very often they will line themselves up only 200-240' apart. There seems to be a subjective inclination to want to be thorough. This results in the operation leader thinking that the teams are using a wider spacing than they really are. This can be a source of error when attempting to assign a POD to a searched area.

Difference Between Thoroughness and Probability of Detection:

Probability of Detection (POD) is a number which would describe the quality of a search for a whole area. The area would usually be searched by a number of parallel sweeps by several teams. Thoroughness, as defined in this report, is an indicator of the quality of one team-sweep. They differ in one way. POD can never exceed 100% (you can't find more people in an area than are in the area.) Thoroughness, as explained earlier, can exceed 100%: if a team finds 5 out of 5 of the subjects within its path plus one other off the side of its sweep, its thoroughness will be 6/5 or 120%. There is nothing wrong with this: an object found to the side of a team is a legitimate find and should be reflected in any measure of the grid method used. Probability of Detection refers to a whole area searched by many sweeps: thoroughness refers to the area covered by one sweep.

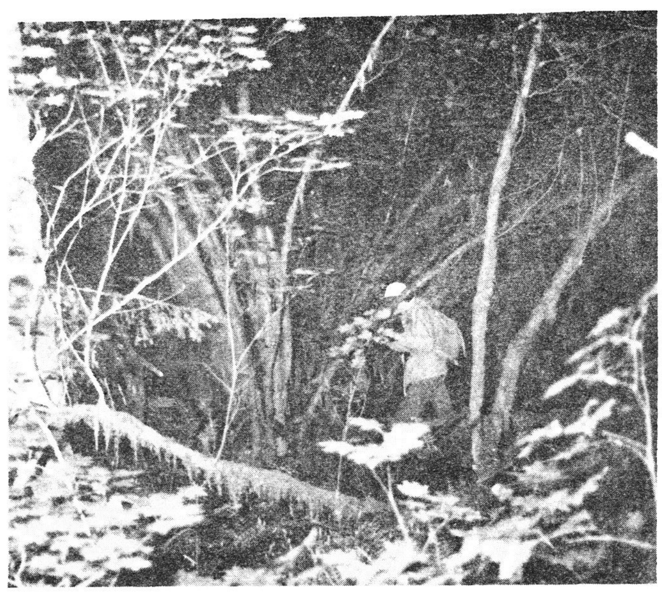
The best way to obtain a POD measure would be to search a large area using several teams. As each subject is found he would be removed. If a subject is found to the side of a team, he would be counted but would not remain to be counted by the team whose path he occupies. The method is simple enough but the resources required to sample several terrain types, several grid types, by day & night would be massive. The method used in this experiment was the best one for measuring team performance but not the best to determine POD's. An adjustment had to be made in order to use this data to estimate a POD. The method used was as follows:

$$\text{POD} = \frac{\text{No. objects found}}{\text{No. objects in team's path + no. objects found to side of team}}$$

Example: A team found 5 out of 8 objects in its path plus 2 objects to the side of its sweep.

$$\text{POD} = \frac{5 + 2}{8 + 2} = \frac{7}{10} = 70\%$$

Unlike thoroughness, this definition cannot exceed 100%. It, therefore, becomes a better measure to use as a POD. This difinition of POD is not the best, but it appears to be the best one obtainable from this experiment. This means that there will be some error in using the POD values listed here on real searches. However, there are already other error sources (mentioned above) which more seriously effect the usability of this data on real operations. In an attempt to make searching a more precise science, we still have a way to go.



Probability of Detection For Multiple Sweeps of the Same Area

The National SAR Manual (6) describes a method to estimate the Probability of Detection (POD) when the same area is searched two or more times; its discussion was largely confined to air and sea searches. Earlier this year, Bill Syrotuck (3) applied the same idea to ground searching. The concept of multiple sweeps of the same area is now taking on a new importance. If, as demonstrated here, non-thorough methods have a place in ground searches, there follows the question of how to improve the probability of detection in likely search areas as manpower becomes available. The obvious solution is to re-search the areas. However, it is not always necessary to re-search the same area with a very thorough method in order to achieve a high probability of detection. For example, Say a 60' grid was used to search a suspected area (POD: 71%) Say further that the operation leader feels that the area should be searched to at least a 90% POD. A second search using the 60' spacing would be sufficient. (Two 60' grids of the same area produces a 91% POD.) A second search using a 20' spacing would produce a POD of 98%; however, it would require 3 times the man-hours as the 60' grid.

For a more detailed description relating POD, manpower requirements, and search time, the reader is referred to Bill Syrotuck's report (3); it should be considered required reading by operation leaders.

PROBABILITY OF DETECTION TABLES FOR MULTIPLE SWEEPS OF THE SAME AREA

The tables on the next page, based only upon the data from this experiment (unconscious and conscious persons combined), provide a means of estimating the POD when the same area is searched up to 3 times.

Examples:

A 100' grid followed by a 20' search (both daytime) yields a POD of 96%.

A single night time search using a 60' spacing produces a POD of 52%.

A 100' grid at night followed by two 60' sweeps during the day produce a 94% POD.

PROBABILITY OF DETECTION TABLES
For multiple sweeps of the same area

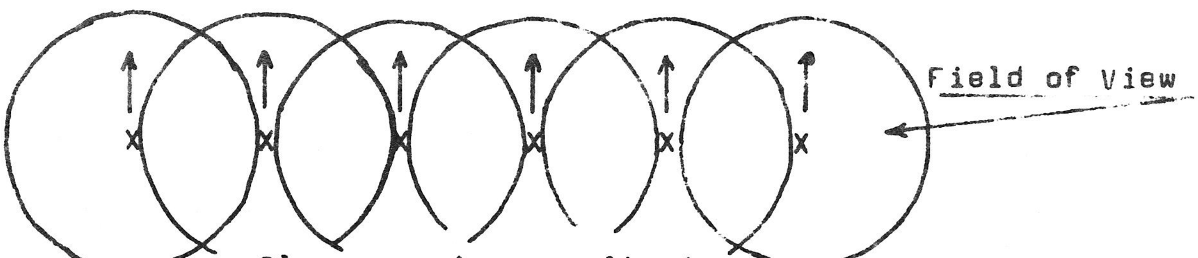
Based upon: 1. Western Washington thick brush and tree cover.
2. 50/50 combination of conscious and unconscious subjects.

SEQUENCE OF SWEEPS (No. indicates between-man distance. (ft.))	PROBABILITY OF DETECTION (%) All Daytime Sweeps	First sweep night time	First two sweeps night time	All Sweeps Night time
20	92	81	81	81
60	71	52	52	52
100	53	35	35	35
20+20	99	98	97	97
20+60	98	95	91	91
20+100	96	91	88	88
60+20	98	96	91	91
60+60	91	86	77	77
60+100	86	78	68	68
100+20	96	94	88	88
100+60	86	81	68	68
100+100	78	69	57	57
20+20+20	99	99	99	99
20+20+60	99	99	99	98
20+20+100	99	99	98	98
20+60+20	99	99	99	98
20+60+60	99	98	97	96
20+60+100	99	97	96	94
20+100+20	99	99	99	98
20+100+60	99	97	96	94
20+100+100	98	96	94	92
60+20+20	99	99	99	98
60+20+60	99	99	97	96
60+20+100	99	98	96	94
60+60+20	99	99	98	96
60+60+60	98	96	93	89
60+60+100	96	93	89	85
60+100+20	99	98	97	94
60+100+60	96	93	91	85
60+100+100	94	90	85	79
100+20+20	99	99	99	98
100+20+60	99	97	96	94
100+20+100	98	97	94	92
100+60+20	99	98	97	94
100+60+60	96	94	91	85
100+60+100	94	90	85	79
100+100+20	98	97	96	92
100+100+60	94	91	87	79
100+100+100	90	85	80	72

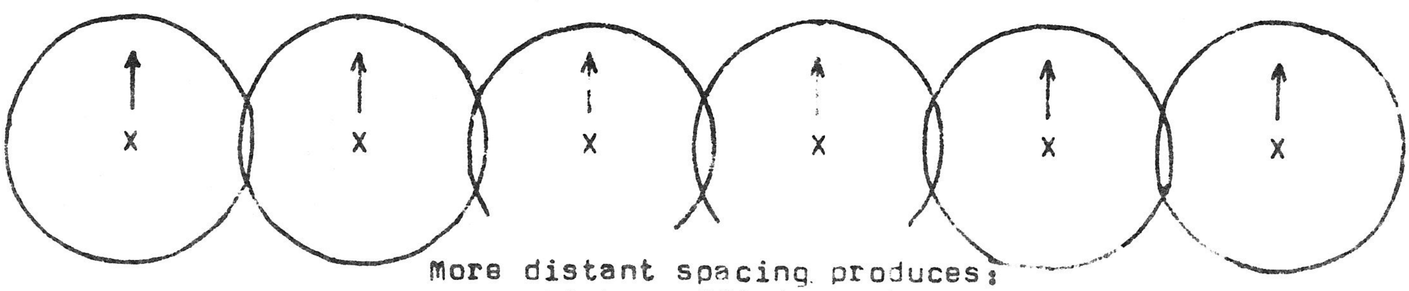
The "Most Efficient" Search Method
A Theoritical Discussion

As mentioned in the introduction, the concept of widely spaced team members rapidly searching a large area as being more likely to produce results within a limited amount of time is not new. All that was done here was to set down the terms a little more precisely and then test the theory to see if it really worked that way. The answer came back in the affirmative; wide spacing is more efficient (at least by day) though less thorough.

It isn't hard to explain why. If team members are close together, there is considerable overlap in their field of view. It is inefficient to have several persons doing the same job; for thoroughness it is the other way around.



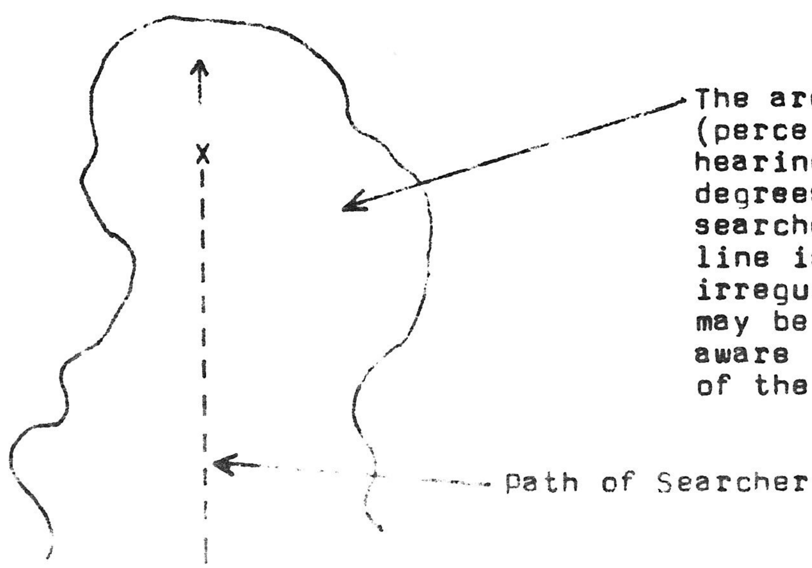
Close spacing results in:
Low efficiency but
High thoroughness



More distant spacing produces:
Higher efficiency but
Less thoroughness

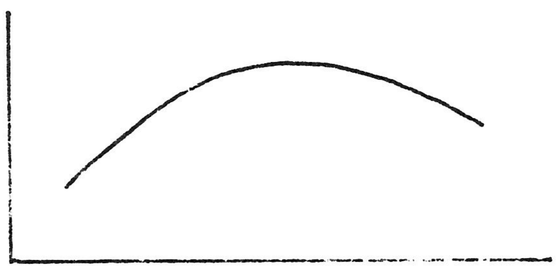
In the above diagrams, a circle represented the searcher's field of view. Actually, the searcher's field of view is not circular - nor is it limited to vision. All of the senses are available and may play a role in the detection of a lost person or clue. Logic dictates that vision and hearing are probably the most useful.

Using vision and hearing, the searcher becomes aware of things happening around him at varying distances and with varying degrees of clarity. The area searched by these senses is not uniform in size. In a clearing, the visual area increases; in heavy trees the area from which the searcher could detect a sound diminishes. Even if the searcher walks a straight line, the area he searches is constantly changing in shape & size.



One might be tempted to advance the argument that the next step would be to measure the size of these irregular shaped fields of vision/hearing under a variety of conditions. With that knowledge, searchers could be spaced so that there was minimum overlap in their respective fields; this would be the "most efficient" of all grid methods.

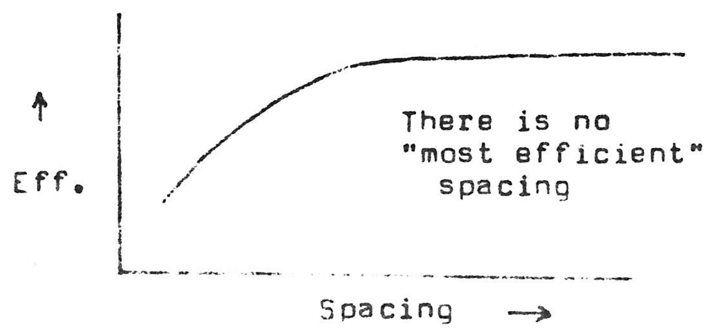
Actually that's impractical and unnecessary. A more realistic next step will be to teach other SAR people, sheriff duputies, etc. that non-thorough sweep searches have a place in search & rescue. The quest for the ultimately efficient search method is of no interest to he who sees no value in it. Besides, at least in theory, there is no "most efficient" method.



Usually an efficiency curve looks like this.

Actually, using the definition given here, efficiency will never "peak out" and begin to decline as spacing increases. It just approaches some upper limit.

Theoretical search efficiency curve.



What happens is that once the spacing is sufficient to prevent overlaping between fields of vision/sound, thoroughness will decline at the same rate as area size increases. The two variables compensate for each other.

If spacing is doubled, the area size is doubled but thoroughness is cut in half; result - no change in efficiency.

If spacing is tripled, the area size is tripled but thoroughness is cut by 3; result - no change in efficiency.

Etc.

Implications For Search Operations: Night Searching

Traditionally, operation leaders have been reluctant to send teams out at night. Fear of unseen obstacles (cliffs, mine shafts, etc.) was often given as a reason. More often it was due to a feeling that night searches were ineffective. However, to rule out night searching in the Pacific Northwest is to eliminate a lot of search time. In bad weather (which seems most of the time) hypothermia usually kills within 48 hours; this doesn't leave much daylight, especially during the winter months. Realistically, we are finding that it sometimes becomes a choice between conducting a night search or a body search. There is so little time available that the night must be used.

This research showed that night searches are less effective than during the day; this doesn't mean that night searches are ineffective. If a60' grid recovers 50% of the subjects at night, that's not bad. If the alternative is no search, the recovery rate will be 0%. Searches for the hypothermic subject require an all-out effort fast; the night time has to be used. The value of this research lies in the fact that it yields some indication of the quality of the search; as the area is checked off on the map an indication of the POD will tell how well it was searched. Later, the area can be re-searched if appropriate.

Dennis Kelley (1) described the results of night searches in Southern California. 60% of their finds were at night. The ability of the lost subject to see the lights of approaching searchers was given as one reason for the success rate. Another reason was the ability to detect tracks with a flash light held at low angles. The difference between the results of this experiment and the apparent success of night searching in Southern California can probably be explained by the topography and gound cover. The conclusions obtained here ought to be typical for this area; there appears reason to question how well it can be generalized to other areas.

Implications For Search Operations: Search Tactics

Dennis Kelley had described a 5-mode system of search tactics.(1)

1. Preliminary mode
2. Confinement
3. Detection
4. Tracking
5. Evacuation

The second mode, confinement, is a relatively new one to those in the Northwest; it is probably one of the best ideas to come along in years. Confinement simply means that an effort is made, early in the operation, to prevent the subject from wandering outside a suspected search area. Suggested methods include track traps, road and/or trail blocks, lookouts & camp-ins. Recently, the use of tagged string lines to form a boundary that the lost person would follow to safety has been proposed.(5)

Sweep searching falls within the Detection mode. It is here that this research would have application. The following tactics are suggested:

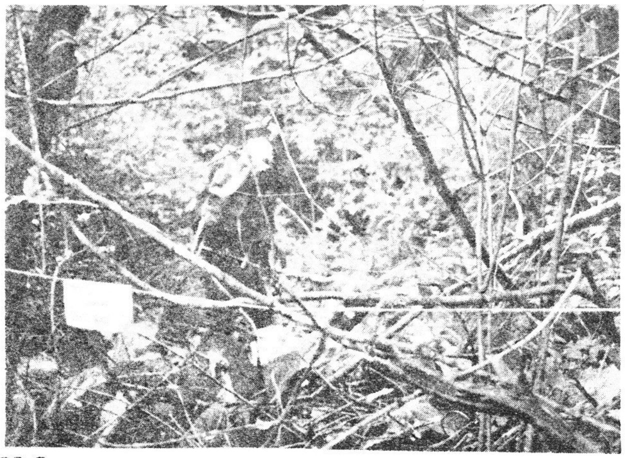
Suggested tactics - Detection mode

Type I Search - Quick informal check of the most likely areas. (also called reconnaissance or hasty searching.)

Type II Search - The criteria is efficiency; a fast systematic check of large areas using sweep methods which produce the highest results per man-hour of effort. (also called open grids.)

Type III Search - The criteria is thoroughness; a slower highly systematic search of smaller areas using thorough sweep methods. (also called close grids.)

This naming system, used by ESAR for some years, was adopted because it generally corresponds to the stages of a developing search operation: Type I usually preceeds Type II, Type II comes before Type III.



TYPE I METHODS:

Objectives: 1. A quick check of specific high probability areas.
2. Obtain information about the search area:

When used: 1. In the early stages of a search.

2. Anytime to check on unconfirmed sightings or to re-check high-probability sites.

Methods: Small highly mobile teams check out:
a. Roads
b. Trails
c. Drainages
d. Ridge areas
e. Buildings
f. Hazards
g. Others

TYPE II METHODS:

Objective: A rapid check of large areas.

When used: 1. In the early stages of a search operation especially if the time frame for victim survival is short.

2. In those situations where the search area is large, no particularily likely areas can be identified, and there is insufficient man-power to cover it thoroughly.

Methods: Sweep searching at wide spacing. Very wide spacing can be accomplished by autonomous 3-man teams working parallel compass bearings at wide intervals.

These methods can cover large areas rapidly; they produce the highest probability of making a find per man-hour of time invested.

Note: Because these methods are not thorough, it is absolutely essential that, as the area is marked off on the operations map, a probability of detection estimate be recorded also. No area must be represented to be searched more thoroughly than it really was.

TYPE III METHODS

Objective: A thorough search of specified areas.

When used: 1. When Type II methods have been tried but the probability of detection was lower than desired.

2. When the search area is limited and the available manpower is large.

Methods: Sweep searching at close spacing.

There is no clear line that separates Type II and Type III methods: each can cover a variety of spacings within a general range.

As mentioned, there are essentially two ways to increase the probability of detection (POD).

1. Use a very thorough method. (Type III)

2. Re-search the same area, possibly several times, with less thorough methods. (Type II)

The choice will usually depend upon manpower and search time available.

Decision Making

A very practical problem in search management is knowing when to use which method and where. There is a process that can be used in this decision making,(1) however, it relies upon someone making a presumption as to how likely it is for the lost person to be within various portions of the search area. It involves the following formula:

Probability of finding the subject	=	Probability of the subject being within the searched area	X	Probability of detection in searching the area

Example: If there is a 50% probability that the subject is within a certain area and the area is searched with a 70% POD, then there is a 35% chance that a search of the area will result in finding the subject.

$$.35 = .50 \times .70$$

The following example will illustrate how this method can be used in decision making.

Problem: A nine square mile search area.

It is estimated that there is a:

15% probability that the subject is in area #1.

25% probability that the subject is in area #2.

35% probability that the subject is in area #3.

The area sizes are:

Area #1 = 1 sq. mi.

Area #2 = 3 sq. mi.

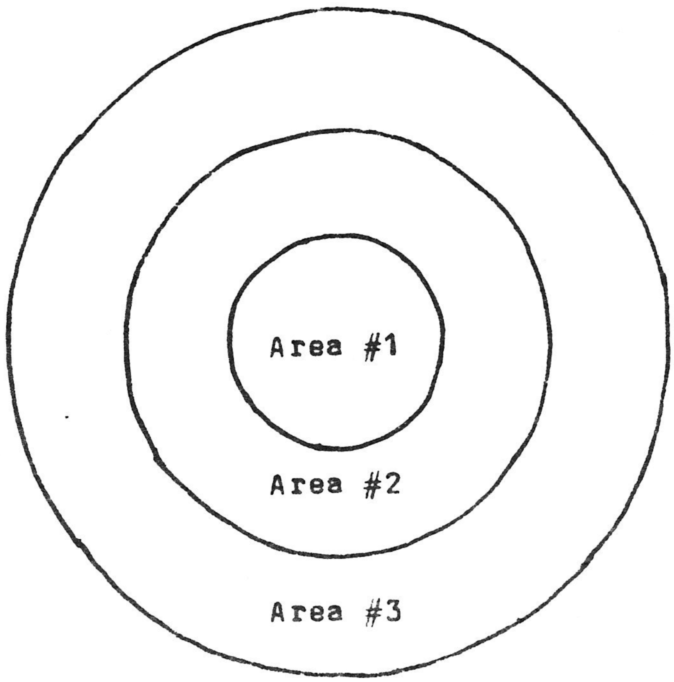
Area #3 = 5 sq. mi.

There is sufficient manpower to do any one of the following before the lost person is likely to die.

20' grid (POD=.92) - 1 sq. mi.

60' grid (POD=.71) - 3 sq. mi.

100' grid (POD=.53) - 5 sq. mi.



3 options come quickly to mind:

1. Search area #1 with 20' grid.
   Probability of finding the subject = .15 X .92 = 13.8%

2. Search area #2 with 60' grid.
   Probability of finding the subject = .25 X .71 = 17.75%

3. Search area #3 with a 100' grid.
   Probability of finding the subject = .35 X .53 = 18.55%

Of the 3, #3 appears most likely to find the lost person. Actually there are a great many more options:

4. Search all of area 1 and 2/3 of area 2 with a 60' grid.
   Probability of finding the subject =
   (.15)(.71) + (2/3)(.25)(.71) = 22.5%

5. Search all of area #1 & #2 and 1/5 of area #3 with a 100' grid.
   Probability of finding the subject =
   $(.15)(.53) + (.25)(.53) + (1/5)(.35)(.53) = 24.9\%$

6. Search all of area #1 with a 60' grid, all of area #2 with a 100' grid, and 1/15 of area #3 with a 100' grid.
   Probability of finding the subject =
   $(.15)(.71) + (.25)(.53) + (1/15)(.35)(.53) = 25.14\%$

There are still other combinations that could be tried. More work needs to be done with this approach in order to rapidly identify the most productive combinations within the setting of a search base. Several people are working on this. If the reader has a talent for mathematics, here is a worth-while problem to tackle.

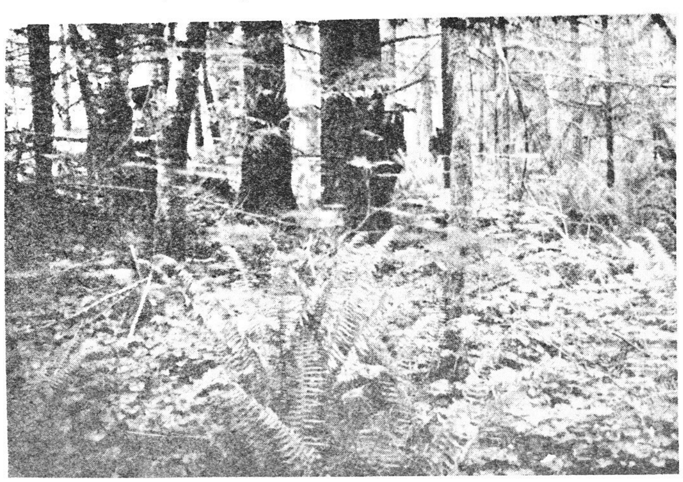
This approach to decision making depends upon two inputs:

1. Reasonable POD estimates - the tables included in this report may be adequate for thick brush and trees but what about other kinds of terrain?

2. Resonable estimates of the probability that the lost person is within various portions of the search area.

Of the two, the latter is the most difficult to pin down. For now, the search director will have to make subjective estimates as best he can. (Actually, no matter how inaccurate, he tends to make such estimates anyway: the only new thing is to plug them into a formula.) Last year Bill Syrotuck (4) published a report which was a deliberate effort to show where lost persons are most likely to be found; this is helpful. The Mountain Rescue Association is currently collecting data that can be used for a similar purpose. This will probably never become an exact science but a certain amount of progress can be expected.

Those who would like a more detailed description of mathematics applied to search theory are referred to the writings of Rex Farquhar and Dennis Kelley.(1)



References

(1) Kelley, Dennis, Mountain Search For the Lost Victim, 1973.
P.O. Box 153 Montrose, California. 91020 $4.50

(2) May, W.G., Mountain Search & Rescue Techniques, 1973.
P.O. Box Y, Boulder, Colorado. 80302 $4.00

(3) Syrotuck, William G., Some Grid Search Techniques for Locating Lost Individuals In Wilderness Areas, 1974.
Arner Publications, Rome, NY.

(4) Syrotuck, William G., A Statistical Analysis of Lost Persons in Wilderness Areas, Number Two. 1973.
Arner Publications, Rome NY. $2.50.

(5) Wartes, Jon & Rengstorf, Bill, The Use of String Lines for Search & Rescue. 1973. Western Region Explorer Search & Rescue, 790 Lucerne Dr., Sunnyvale, California. 94086
$.50

(6) ____________, National Search & Rescue Manual, 1973.
U.S. Government Printing Office, Washington D.C. 20402.
$4.00

EXPLORER SEARCH & RESCUE

"SUBJECT" INSTRUCTIONS

NAME ______________________ SUBJECT # ________

PLEASE READ CAREFULLY:

1. Your assignment, should you decide to accept it, is to stay within area _____(day search) and area ______(night search.) You may place yourself anywhere within the above area. You may move around from time-to-time (keep it to a minimum) but move only when no search team is in sight. It is extremely important that you do not move outside your area.

2. As teams approach, you are to assume the role of the following (checked.)

   ☐ Unconscious person - motionless and silent. You are not to hide but seek any shelter or comfort that a lost person might make use of prior to becoming unconscious.

   ☐ Conscious person - Down and unable to move but able to respond vocally as a team approaches. When a team approaches close enough that you can see or hear it, call out to the team. Use a voice volume that you would normally use if you were carrying on a conversation with a person 20' away. Use any other actions that might attract the team but remain down in one position.

3. When found, give your "subject" number to the team member who found you. He will write it down and the team will continue on. Re-assume your position and wait for the next team. You will probably be found several times through the course of the search. The team assignments have been scheduled such that it is improbable that the same team member will pass your way a second time.

4. Please stay separated from any other "subjects." The rule to follow is "if two subjects are close enough together that the finding of one might influence the finding of the other, they are too close together."

5. Do not return to base until all teams have finished. This is very important! When all teams have finished, one of the following signals will be given:

   1. Police siren
   2. 4 blasts on a car horn.

THANK YOU FOR HELPING. YOU ARE MAKING A VERY DEFINITE CONTRIBUTION TO AN IMPORTANT PIECE OF RESEARCH. THE RESULTS MAY VERY WELL LEAD TO THE SAVING OF LIVES.

EXPLORER SEARCH & RESCUE

TEAM ASSIGNMENT SHEET

TEAM#______ TEAM LEADER: ______________________________

		Grid Type	Starting End	Starting Pegs
DAY TIME				
	1st Sweep	__ Compass ___		
	2nd Sweep	__ Compass ___		
	3rd Sweep	__ Compass ___		
NIGHT				
	1st Sweep	__ Compass ___	A	
	2nd Sweep	__ Compass ___	A	
	3rd Sweep	__ Compass ___	A	

GRID TYPES:
X: Flanker O: Compass man

6 Compass 20

↑ ↑
X O X X O X
20°

6 Compass 60

↑ ↑
X O X X O X
60°

3 Compass 50
(Two three man teams @ 300° center-to-center.)

↑ ↑
X O X X O X
50° 300°

EXPLORER SEARCH & RESCUE

DAYTIME SEARCH SCHEDULE

Team #	FIRST SWEEP Grid Type	Starting End	Start Pegs	SECOND SWEEP Grid Type	Starting End	Start Pegs	THIRD SWEEP Grid Type	Starting End	Start Pegs
1	Close	A	Blue 1-6	Int.	B	Orange 1-6	Open	A	Yellow 1-6
2	Open	B	Yellow 1-6	Int.	A	Red 1-6	Close	B	Blue 25-30
3	Int.	A	Red 1-6	Open	B	Yellow 1-6	Close	A	Blue 19-24
4	Close	B	Blue 25-30	Open	A	Yellow 1-6	Int.	B	Red 1-6
5	Int.	A	Orange 1-6	Close	B	Blue 1-6	Open	A	Yellow 1-6
6	Open	B	Yellow 1-6	Close	A	Blue 25-30	Int.	B	Red 1-6
7	Close	A	Blue 7-12	Int.	B	Orange 1-6	Open	A	Yellow 1-6
8	Open	B	Yellow 1-6	Int.	A	Orange 1-6	Close	B	Blue 1-6
9	Int.	A	Red 1-6	Open	B	Yellow 1-6	Close	A	Blue 13-18
10	Close	B	Blue 19-24	Open	A	Yellow 1-6	Int.	B	Red 1-6
11	Int.	A	Orange 1-6	Close	B	Blue 7-12	Open	A	Yellow 1-6
12	Open	B	Yellow 1-6	Close	A	Blue 19-24	Int.	B	Red 1-6
13	Close	A	Blue 13-18	Int.	B	Red 1-6	Open	A	Yellow 1-6
14	Open	B	Yellow 1-6	Int.	A	Red 1-6	Close	B	Blue 25-30
15	Int.	A	Red 1-6	Open	B	Yellow 1-6	Close	A	Blue 19-24
16	Close	B	Blue 1-6	Open	A	Yellow 1-6	Int.	B	Orange 1-6
17	Int.	A	Orange 1-6	Close	B	Blue 13-18	Open	A	Yellow 1-6
18	Open	B	Yellow 1-6	Close	A	Blue 7-12	Int.	B	Orange 1-6
19	Close	A	Blue 25-30	Int.	B	Red 1-6	Open	A	Yellow 1-6
20	Open	B	Yellow 1-6	Int.	A	Orange 1-6	Close	B	Blue 1-6
21	Int.	A	Red 1-6	Open	B	Yellow 1-6	Close	A	Blue 25-30
22	Close	B	Blue 7-12	Open	A	Yellow 1-6	Int.	B	Orange 1-6
23	Int.	A	Orange 1-6	Close	B	Blue 7-12	Open	A	Yellow 1-6
24	Open	B	Yellow 1-6	Close	A	Blue 1-6	Int.	B	Orange 1-6
25	Close	A	Blue 19-24	Int.	B	Red 1-6	Open	A	Yellow 1-6

EXPLORER SEARCH & RESCUE
"SUBJECT" ROSTER AND ASSIGNMENT SCHEDULE

NAME	ADDRESS	CITY	ZIP	PHONE	ASSIGNED AREA	ASSIGNED ROLE
					1A	U (unconscious)
					2A	C (conscious)
					3A	U
					4A	C
					5A	U
					1B	C
					2B	U
					3B	C
					4B	U
					5B	C
					1A	C
					2A	U
					3A	C
					4A	U
					5A	C
					1B	U
					2B	C
					3B	U
					4B	C
					5B	U

Acknowledgements

Over 3,400 man-hours of work went into the preparation, administration, and evaluation of the research reported here. Greatful appreciation is expressed to:

Jim Macartney - The first person to articulate the concept of efficiency.
John Macartney - Operation Leader for this project.
Willard & Dottie Krigbaum - Site selection & preparation.
Pat Nelson - Subject recruiting & Commissary
Penny Woodard - Commissary
Lee Hahn - King County Police
Harry Shook - Weyerhaeuser Co.
Jim & Nancy Jo Granger - Communications
Jim Cleary - Field Leader
Al Albright - Field Leader
Ed Thompson - Field Leader
Tom Miner - Field Leader
Bill Rengstorf - Field Leader & Photography
George Uchida - Photography
Mel Abbott - Aerial Photography
Miles Hanchett - Experimental Design & Data Collection
Barry Nelson - Keypunch
Dennis Bough - Computer
Warren Fulton - Computer
The 36 "brush monkeys" who served on teams.
The 45 ESAR family members & friends who served as subjects.