A Simple Guide to Conducting Ground Search and Rescue Detection Experiments

Volume II

Appendixes

Prepared for

U.S. Department of Homeland Security
United States Coast Guard
Office of Search and Rescue (G-RPR)
Washington, D.C. 20593-0001

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Potomac Management Group, Inc.
20 May 2006

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Appendix A. Modifications for Other Resources

Ground search and rescue uses a wide vary of resources. Some resources primarily find and collect investigative information and it would be difficult or inappropriate to apply effective sweep width theory. Therefore man-trackers, investigators, and tracking/trailing dogs are resources that do not require sweep width experiments. Several other common resources involve humans using visual sighting except the human sensor is located on some type of moving platform. Experiments to determine their effective sweep width values involve only minor modifications to these outlines. Finally experiments using air resources and air-scent dogs require some more extensive modifications and will only be outlined briefly.

Mounted (Horses): The track needs to be appropriate for the skill level of the riders that will be used. The track does not have to be limited to roads and trails if using skilled riders. The placement of search objects will follow all the normal procedures. One major modification is making the Total Track Distance 25-meter/yard flags readable while still mounted. This can be accomplished in several manners. Some suggestions include, using paper plates marked with the distance staked down with the surveyor's flags. This would also allow the numbers to be read more easily. Plates may only need to be placed every 50/100 meters/yards. Paper plates that hold up to rain are also available and may be more appropriate. Flagging tape placed at the rider's height and marked with distance numbers may also be appropriate. A second major modification involves data collection. While mounted it is difficult to write on the detection log. Possible solutions include pilot clipboards or kneeboards (designed to be strapped to a pilot's leg). Several sources can be found on the web.

Figure A-1. Illustration of a Pilot's Clipboard or Kneeboard.

Figure A-2. Alternative Total Track Distance Method Using Flags and Plates.

Trail Runners (ATV, Snowmobile, Vehicles, Motorcycle, Bicycle): All of these resources are typically tasked to run fixed trails or roads. However, in some circumstances they are asked to search lateral distances off-trail or road. Modifications will require changes in AMDR, selection of track, and marking total track distances along the track. The eight-legged star pattern of a typical AMDR may be difficult to perform since it requires cross-country travel and these mechanized resources require trails or roads. However, since the human eye is still the predominant sensor ground-based AMDR values should provide sufficient lateral ranges for the experiment to succeed. However at typical speeds search objects would be passed too quickly and require far too many objects to make an experiment last an hour. The easiest modification is to take the IDEA generated total track line distance and multiply it by a correction factor. The correction factor would simply be the average speed of the special resource divided by the average speed of a ground searcher (1.75 km/hr). So if an ATV is searching at 20km/hr then the correction factor would be 11.4. So if IDEA generates a course that is 2 km for a ground searcher with 36 search objects, the course would be extended to 22.8 km with the same number of search objects. The marked flags could also be spaced out accordingly. Instead of marked flags every 25 meters they could be spaced out to every 100 meters. Paper plates to make the numbers more readable while staying mounted on the bike should be the same as shown in Figure A-2.

Air Resources: Air resources would require more extensive modification to the experiment. Anyone contemplating an air experiment (rotary or fixed wing) should contact the experimental design team listed on page 41.

Air-Scent Dogs: It may be possible to design and conduct experiments to determine the effective sweep width for an air-scent dog team. However, the experimental design is different from the ground-based experiments. The search object must be an actual human being. A GPS unit that is tracking the actual track taken by the dog must be used. The definition of "detection opportunity" and the method to calculate lateral range require careful definitions. Defining a detection and non-detection are critical to the experiment success. The environmental variables that need to be included also require the length of the shadow of a six-foot pole on level ground and cloud cover. Pilot experiments are still underway to better define all the required elements of an air-scent dog team experiment. Anyone contemplating an air-scent dog experiment should contact the experimental design team listed on page 41.

Appendix B. Search Object Construction

This appendix describes how to build inexpensive, disposable, lightweight search objects that are representative of adults, children, and clues.

Brown or Green Conditions

Adult High-Visibility Search Object	**Adult Medium-Visibility Search Object**	**Adult Low-Visibility Search Object**
Required Materials • White Coveralls • Orange Vest • One cardboard shipping tube for leg • Rectangular cardboard box(es) for Chest • Tent stake **Assembly instructions** 1. Assemble cardboard boxes 2. Hit corners of leg tube on rock to make easier to insert into coveralls. 3. Insert leg in coveralls 4. Insert chest boxes in. 5. Zip up coveralls 6. Place orange vest on 7. Stake in place. Note: Disposable painter's coveralls are recommended and are quite inexpensive if purchased in quantity.	**Required Materials** • Blue Coveralls • One cardboard shipping tube for leg • Rectangular cardboard box(es) for Chest • Tent stake **Assembly instructions** 1. Assemble cardboard boxes 2. Hit corners of leg tube on rock to make easier to insert into coveralls. 3. Insert leg in coveralls 4. Insert chest boxes in. 5. Zip up coveralls 6. Place on ground white zipper side down. 7. Stake in place	**Required Materials** • White Coveralls • Camouflage Paint • One cardboard shipping tube for leg • Rectangular cardboard box(es) for Chest • Tent stake **Assembly instructions** 1. Paint white coveralls with camouflage spray paint (Deep Forest Green #1919 or Earth Brown #1918) available in hardware stores. One can paints two search objects. Allow 2 hours to dry. 2. Assemble cardboard boxes 3. Hit corners of leg tube on rock to make easier to insert into coveralls. 4. Insert leg in coveralls 5. Insert chest boxes in. 6. Zip up coveralls 7. Bring paint to touch up any white spots 8. Stake in place
		

Construction of child sized search objects takes advantage of the same adult coveralls. Only the cardboard is not required. The stake should be through the center to hold in place.

Child High-Visibility Search Object	**Child Medium-Visibility Search Object**	**Child Low-Visibility Search Object**
Required Materials • White Coveralls • Tent stake **Assembly instructions** 1. Take adult white coveralls and fold in head, legs, and then fold in half lengthwise. 2. Fold in half widthwise. 3. Search object should be dimensions 50 cm (20 in) long, 30 cm (12 in) wide, and 13 cm (5”) high. 4. Stake in place.	**Required Materials** • Blue Coveralls • Tent stake **Assembly instructions** 1. Take adult white coveralls and fold in head, legs, and then fold in half lengthwise. 2. Fold in half widthwise. 3. Search object should be dimensions 50 cm (20 in) long, 30 cm (12 in) wide, and 13 cm (5”) high. 4. Place zipper down. 5. Stake in place	**Required Materials** • White Coveralls • Camouflage Paint • Tent stake **Assembly instructions** 1. Use painted green adult coveralls and fold in head, legs, and then fold in half lengthwise. 2. Fold in half widthwise. 3. Search object should be 50 cm (20 in) long, 30 cm (12 in wide, and 13 cm (5”) height 4. Bring paint to touch up any white spots 5. Stake in place
		

White gloves are used as a standard clue since they are inexpensive and light. It has been found cheaper to purchase white gloves and paint them, rather than to buy colored gloves.

<table>
<tr>
<td>Clue High Visibility

Required Materials
White glove
Red Glowing Orange Fluorescent #3101 Spray Paint
Instructions:
Paint the glove fluorescent orange</td>
<td>Clue Medium-visibility

Required Materials
White glove
Blue Spray Paint (Regal Blue Gloss #1901)
Instructions:
Paint the glove blue</td>
<td>Clue Low-visibility

Required Materials
White glove
Camouflage Spray paint (either Deep Forest Green #1919 or Earth Brown #1918)
Instructions:
Paint the glove brown or green.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</table>

Snow (White) Conditions

If snow is on the ground, the colors of the search objects need to be altered to better represent high, medium, and low visibility. For the adult high visibility a second orange vest is added to the coveralls. The adult medium visibility remains the same with the blue coveralls. The low visibility changes to white coveralls or glove.

Adult High Visibility	**Adult Medium Visibility**	**Adult Low Visibility**
 Instructions: Use white coveralls, adding two orange vests.	 Instructions: Use blue coveralls	 Instructions: Use white coveralls without vest.
Child High Visibility 	**Child Medium Visibility** 	**Child Low Visibility** 
Clue High Visibility 	**Clue Medium Visibility** 	**Clue Low Visibility** 

Appendix C. Construction and Use of Robel Pole (Obstruction Pole)

The Robel pole is used to objectively measure the height of ground cover for use on the environmental measures form. The Robel pole is also referred to as an obstruction pole in the scientific literature. While it can be constructed from many different materials the method described will minimize the amount of materials that need to be carried into the field (the shipping tube doubles as the leg of the adult manikin used in the AMDR data collection).

Construction:

Materials:

- 5.2 meters of parachute cord or string.
- Shipping tube (same as used for leg of adult search object)
- Meter ruler
- Red or Black permanent magic marker
- Tape or stapler.

1. Gather the required materials.
2. On the shipping tube, use the magic marker to mark every 10 centimeters (black electrical tape may also be used to mark every 10 centimeters). Label each 10 centimeter mark from the bottom to the top 1, 2 ,3 etc. (Figure B-1).
3. If the environment has shorter vegetation, also mark the bottom 20 centimeters in one centimeter increments (Figure B-2.).
4. Attach 5.2 meters of string or parachute cord to the bottom of the tube using a stapler or tape. Measure 4 meters of string away from the tube and tie a knot. From the knot, measure 1 meter and trim the remaining string so that it is exactly one meter from the knot.

Figure B-1 shows the shipping tube marked in ten centimeter increments. Figure B-2 shows a close-up of the tube with the one-centimeter increments for the first 20 centimeters.

Figure B-1. Marked Shipping Tube

Figure B-2. Close-up of Tube

Use of the Robel Pole in the field:

1. Place the Robel Pole at the same spot the search object will be located. It should be flush against the soil. If conditions are windy the Pole may be staked, secured with a heavy object placed in the tube, or held by an assistant.
2. Use the string to move 4 meters away from the tube (four meters denoted by the knot).
3. Stand on the knot and use the remaining one-meter of string to place eye one-meter above the ground.
4. Look at the Robel Pole and note the height (in centimeters) where vegetation completely obscures the scale (Figures B-3 and B-4 give two examples).
5. Record the height on the environmental measurements worksheet in the ground cover block.

Robel Pole Use

While the height of some types of vegetation may actually be taller than the measurements obtained from the Robel pole, the Robel pole provides a more consistent measurement that actually corresponds to the amount of biomass above the ground.

Figure B-3 shows how the Robel pole appears from four-meters away in long grass. Figure B-4. is a close-up of the same photo that shows the 20 and 30 centimeter red lines. The black line shows the maximum view of the tube (use the left side that has the scale). The black line corresponds to 15 centimeters. Figure B-5 shows the Robel pole placed in ivy. The ground cover should be read as 18 centimeters.

Figure B-3. Robel Pole View at Four-Meters.

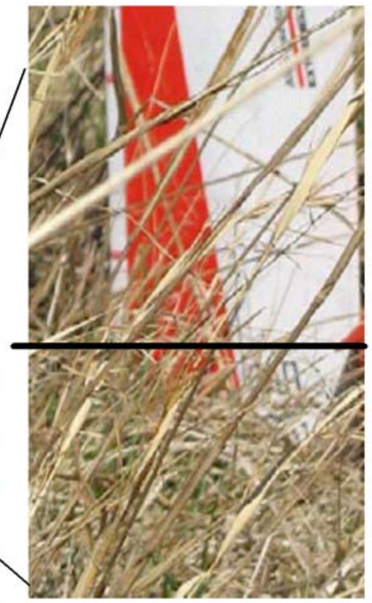

Figure B-4. Robel Pole Close-up.

Figure B-5. Robel Pole in Ivy.

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Appendix D. Materials and Supplies

One-Time Purchase (Capital equipment needed for experiment)

Required Supplies	Source	Stock #	Web	Phone	Cost	Qty	Total Price
Roller Wheel	Forestry Suppliers	39026	www.forestry-suppliers.com/	800.674.5368	$72.00	1	$72.00
Marker Flag carry-case	Forestry Suppliers	39579	www.forestry-suppliers.com/	800.674.5368	$7.90	1	$7.90
GPS – Civilian Grade	Local Sports store					1	
Laser Range Finder - Civilian	Mosquito Creek	7426	www.mosquitocreekoutdoors.com/	800.250.5191	$299.00	1	$299.00
100 foot tape measure	Local Hardware store					1	
Compass with inclinometer	Local Sport store					1	
Lux Meter	Kaito electronics	fx101	www.multimeterwarehouse.com/FX101f.htm		$40.00	1	$40.00
Digital Camera	Local electronics store					1	

	Comments
Roller Wheel	Used to mark length of course, check with local running club
Marker Flag carry-case	
GPS – Civilian Grade	Used to plot course onto topographic map, generally available
Laser Range Finder - Civilian	Used to measure lateral range distance
100 foot tape measure	less ideal substitute for Laser Range Finder
Compass with inclinometer	Used for target placement, readily available
Lux Meter	Used to measure light intensity
Digital Camera	Used to record terrain, readily available

Disposable equipment needed for each experiment

Required Supplies	Source	Stock #	Web	Phone	Cost/Unit	Unit	Qty	Total Price
Human sized target (Blue coveralls)	GSS	COVWC3584	www.gss-store.com/	888-477-0004	$27.50	box 25	1	$27.50
Human sized target (White coveralls)	GSS	COVHB	www.gss-store.com/	888-477-0004	$24.00	box 25	1	$24.00
Paint (determine color)	Local Hardware store				$4.95	can	0.5/target	$40.00
Orange vest	Local Sporting store				$5.00	each	1/target	
Cardboard Boxes (Body, arms, leg)	Local						4/target	
Selected Clue	Local					each	1/target	
Marker Flags (every 25 meters)	Forestry Suppliers	33507	www.forestry-suppliers.com/	800.674.5368	$4.80	100 flags	2	$10.00
Marker Flags (every 500 meters)	Forestry Suppliers	33507	www.forestry-suppliers.com/	800.674.5368	$4.80	100 flags	1	$5.00
Marker Flags (waypoints)	Forestry Suppliers	33507	www.forestry-suppliers.com/	800.674.5368	$4.80	100 flags	4	$20.00
Marker Flags (every 100 meters)	Forestry Suppliers	33507	www.forestry-suppliers.com/	800.674.5368	$4.80	100 flags	1	$5.00
Permanent Marker	Local office supply					each	2	$4.00
Flagging Tape	Forestry Suppliers	57905	www.forestry-suppliers.com/	800.647.5368	$12.24	dozen rolls	1	$24.50
Various Forms	Laser Printer							
Waterproof paper (for forms)	Rite-in-the-Rain	8511	www.riteintherain.com/copierpaper.html	253.922.5000	$23.95	200 sheets	1	$23.95
Waterproof paper (for maps)	I-Gage		www.igage.com/WeatherP.htm		$19.95	50 sheets	1	$19.95
Extra Pens and Pencils	Local office supply							

	Comments
Human sized target (Blue coveralls)	Used for adult sized target, stuffed with cardboard, able to reuse but easier to replace
Human sized target (White coveralls)	Used for both high and low vis adult target. Painted with spary paint for low vis target. Orange vest placed on for high vis
Paint (determine color)	Used for making low-vis target. One can of spray paint makes two adult targets
Orange vest	For High-vis targets only. Can be reused, also worn when setting out search objects
Cardboard Boxes (Body, arms, leg)	For each adult target need at least one large triangular document box for leg, and two rectangular boxes for chest
Selected Clue	Hat and gloves can be purchased locally, buy white and use spray paint as needed
Marker Flags (every 25 meters)	Need 40 flags for every km of course
Marker Flags (every 500 meters)	Need only one unit (100) to mark start, every 500 meters and end
Marker Flags (waypoints)	Depending upon terrain may need 40-280 flags per km of course
Marker Flags (every 100 meters)	Need only one unit (100) to mark start, every 100 meters
Permanent Marker	Needed to mark flags, carry at least two in case one dropped in field
Flagging Tape	Used to initially mark trial
Various Forms	Forms and numbers needed specified in excel worksheet
Waterproof paper (for forms)	Data logger forms and search profile forms needed to be made on waterproof paper
Waterproof paper (for maps)	If passing out color maps made with a inkjet
Extra Pens and Pencils	

The IDEA software will generate the needed amounts of expendable supplies such as search objects, cardboard boxes, flagging tape, and surveyor flags. The formulas are based upon:

- Adult/child size search objects
    - Number of required search objects rounded up to a multiple of 24 (number in box)
    - One cardboard shipping tube per required search object rounded up to a multiple of 12 (number in box). Shipping tubes not required for child sized search objects.
    - Two cardboard "Large Shirt" boxes per adult search object.
    - One stake per search object
    - One orange vest per high visibility search objects (brown or green conditions).
    - Two orange vest per high visibility search object adult (white conditions).
    - One can of Green/brown paint per two low visibility adult search objects (brown or green conditions).
- Surveyor Flags
    - Yellow flags (3 per kilometer)
    - Lime Green flags (40 per kilometer)
    - Red flags (200 per kilometer if dense)
    - Orange flags (10 per kilometer)
    - Flags come in bundles of 100 to the bundle. Colors may be substituted depending upon availability and the type of terrain.
- Flagging tape
    - Three roles per kilometer

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Appendix E. Suggested Experiments

Experiments can be conducted to not only determine effective sweep widths in different terrains but also to compare different resources, search techniques, specialized equipment, and determine correction factors.

While there are many factors that determine where and what type if experiment a team chooses to perform, the first is what best meets the operational needs of the team concerned. Therefore teams should perform experiments in the type of terrain and vegetation they encounter most frequently on actual searches. Undoubtedly some areas will be covered multiple times while other areas still have not determined effective sweep width values. The major need for experiments is to develop preliminary sweep width values for the major types of land classifications. The three most common types of land encountered on searches are the different types of forest. Forests can be further broken down in several different types of Western and Eastern (USA) forests. Each of the forest types are also further refined by differences found in each ecoregion. Therefore experiments will need to be conducted for each forest type in each ecoregion. It goes without saying time of year may have a tremendous effect on the vegetation. Therefore for each area that experiences seasonal variation experiments documenting the green, brown, and white conditions will need to be performed.

National Land Classification Types

- Open Water
- Perennial Ice/Snow
- Low Intensity Residential
- High Intensity Residential
- Commercial/Industrial
- Bare Rock/Sand/Clay
- Quarries/Strip Mines
- Transitional
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub land
- Orchards/Vineyards
- Grasslands
- Pasture/Hay
- Row Crops
- Small Grains
- Urban Grasses
- Woody Wetland

Descriptions of each of the following may be found at the NOAA Coastal Services Center (http://www.csc.noaa.gov/crs/lca/tech_cls.html). Determination of how a site is mapped can be determined using the US National Map (http://nationalmap.gov). Use the landcover layer, then the USGS NLCD checkbox.

Forest Types

Each team would also need to know the effective sweep value for each of the different forest types it encounters. Therefore, an experiment should be done in each of the following forests for each ecoregion (see next page for ecoregions). The US National Grid classifies forest as follows:

Eastern Forest Types

- White-red-jack Pine
- Spruce-fir
- Long lead-slash pine
- Loblolly Pine
- Oak-Pine
- Oak-hickory
- Oak-gum-cypress
- Elm-Ash-Cottonwood
- Maple-Beech-Birch
- Aspen

Western Forest

- Douglas-fir
- Hemlock-Sitka Spruce
- Ponderosa Pine
- Western White Pine
- Lodge Pole Pine
- Larch
- Fir-Spruce
- Redwood
- Chaparral
- Pinyon-juniper
- Western Hardwoods

A map showing the classification of forest is linked in the IDEA software. It can also be found using the US National atlas (http://nationalatlas.gov). Use the biology layer and select forest type.

Ecoregions

Each of these forest types will vary somewhat depending upon the ecoregion; therefore, it is important to state the ecoregion in which the experiment is conducted.

Search incidents on land occur in vastly different types of climate, terrain and vegetation. The best method to easily characterize different types of vegetation is with ecoregions. The U.S. Department of Agriculture Forest Service uses ecoregions developed by Robert Bailey (1995) which are based on climate, vegetation, soil, and terrain—but with emphasis on vegetation and terrain. Ecoregions are broken into four major domains: polar, humid temperate, dry, and humid tropical. Almost all of the continental United States falls into either the humid temperate or dry domains. The domains are then further broken down into Divisions (see table below), which are in turn further broken down into Provinces (Figure 1, p. 11).

100 Polar Domain 120 Tundra Division* 130 Subarctic Division*	**300 Dry Domain** 310 Tropical/Subtropical Steppe Division* 320 Tropical/Subtropical Desert Division 330 Temperate Steppe Division 340 Temperate Desert Division*
200 Humid Temperate Domain 210 Warm Continental Division* 220 Hot Continental Division* 230 Subtropical Division* 240 Marine Division* 250 Prairie Division 260 Mediterranean Division*	**400 Humid Tropical Domain** 410 Savanna Division* 420 Rainforest Division*
* = Divisions that also have a mountain province, which would be indicated by the letter “M” before the division number (e.g., M120 = Tundra Division, Mountain Provinces).	

Maps showing the different ecoregions are linked in the IDEA software and can be found on page 11 (Figure 1) in this guide. Online maps may be found on the national atlas (http://nationalatlas.gov) or world-wide maps may be found at the USDA site (http://www.fs.fed.us/institute/ecoregions/eco_download.html).

Correction Factor Experiments

At this time preliminary data has been collected about individual correction factors (fatigue, morale, height, colorblindness, etc). However, experiments have not been conducted for possible major correction factors to sweep width. Possible correction factor experiments include:

- Light levels (day, twilight, night)
- Visibility (clear, rain, snow, fog)
- Wind

Correction Factor experiments should be conducted via two trials. First the experiment is conducted during optimal conditions and the effective sweep width is determined (using a high-visibility adult search object would be mandatory). Then when the desired environmental conditions exist the experiment would be repeated.

For experiments involving light levels the environmental light levels should be measured with a Lux meter. The brightness of searcher's flashlights should also be recorded. Measurement should be made using the same type of beam used for searching and at a distance of one meter from the light source.

For experiments involving meteorological visibility known calibrated distances to high contrast objects should be used. The meteorological visibility for each searcher should be recorded since it is expected to vary throughout the experiment.

Wind as a correction factor is likely to only play a major role in experiments determining effective sweep widths for responsive subjects.

Appendix F. Forms

The forms used in the IDEA spreadsheet are found on the following pages. The numeral in parentheses after the form title corresponds to the worksheet number in the spreadsheet.

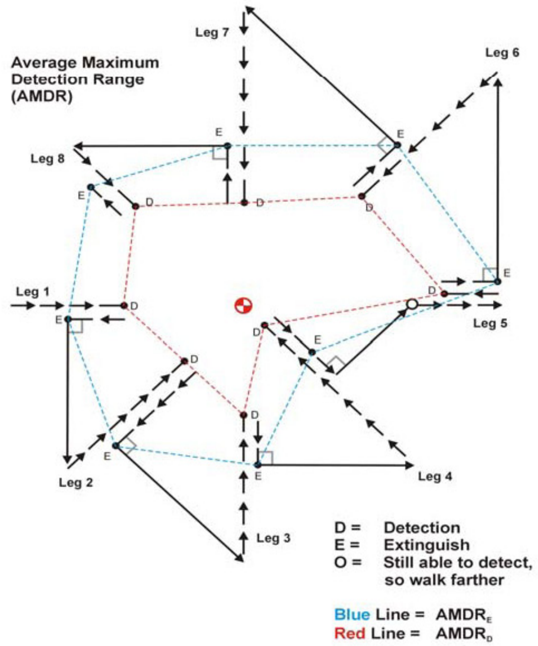
Determining AMDR Worksheet – Adult (6), Child (7), Clue (8)

The Determining Average Maximum Detection (AMDR) Worksheet allows the researcher to determine and document AMDR and other measures to quantitate field visibility. The values entered will automatically be used to determine several other experiment values on later worksheets.

1. Date	2. Time	3. Object Type	4. GPS E	GPS N
5. Location		6. Terrain Type	7. Cloud Cover	8. Precipitation

AMDR Measurements

Starting on Leg 1 move toward the target until the target is detected. Record the distance the target was first detected in the red AMDRd column. Move backwards until the target is no longer seen and record the distance in the blue AMDRe column. Pace the same distance at a right angle to start Leg 2 and repeat the procedure.



High Visibility (normally Orange/white)

Leg #	Trial #1 AMDRd	Trial #1 AMDRe	Trial #2 AMDRd	Trial #2 AMDRe
1				
2				
3				
4				
5				
6				
7				
8				
AVG				
MAX				
AVG				
AVG_{all}	Yards			

Suggested equipment:
Highest visibility target, Laser Range finder, tape measure, GPS, topographic map, Vegetative density board, notebook, pencil, Determining AMDR work-sheet, digital camera, compass.

Medium Visibility (normally blue)

Leg #	Trial #1 AMDRd	Trial #1 AMDRe	Trial #2 AMDRd	Trial #2 AMDRe
1				
2				
3				
4				
5				
6				
7				
8				
AVG				
MAX				
AVG				
AVG_{all}	Yards			

Low Visibility (normally green/brown)

Leg #	Trial #1 AMDRd	Trial #1 AMDRe	Trial #2 AMDRd	Trial #2 AMDRe
1				
2				
3				
4				
5				
6				
7				
8				
AVG				
MAX				
AVG				
AVG_{all}	Yards			

Search Object Location Log (11)

This worksheet allows documentation of the actual placement of objects, way points, legs, and other measurements during the actual setup in the field. This worksheet should be printed prior to setting up the experiment and brought into the field to facilitate field recording. Object Placement & Chart (Worksheet # 10) must also be printed out and brought into the field to determine the targeted object locations. Print on waterproof paper.

1. Date	2. Time	3. Location		4. Name		
5. Object Type # 1	6. Object Type # 2		7. Object Type # 3	8. Object Type # 4	9. Datum	10. Units

Instructions

Log the actual locations based on Worksheet # 10 (Object Placement & Chart). Placement along Track Distance (TD) can be determined by roller wheel or GPS odometer. The lateral range distance should be determined by Laser Range Finder or tape measure.

Suggested Equipment. Laying out the course will require the following: search objects (described in "A Simple Guide to Conducting Ground Search and Rescue Detection Experiments"), stake wire flags, permanent marker, flagging tape, GPS, Laser Range Finder, measuring tape, stakes, reflectors, roller wheel, digital camera, compass, topographic map, pencils, and the following forms on waterproof paper (10. Object Placement & Chart and 11. Search Object Location Log).

Location #	Object Type	Track Distance	Lateral Range	Left - Right	Orientation	Elevation	Verification
Example	*1*	*28*	*17*	*L*	*180*	*Up*	✓
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
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Search Object Location Log (11)

Page 2 of 2

Instructions

Log the actual locations based on Worksheet # 10 (Object Placement & Chart). Placement along Track Distance (TD) can be determined by roller wheel or GPS odometer. The lateral range distance should be determined by Laser Range Finder or tape measure.
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Location #	Object Type	Track Distance	Lateral Range	Left - Right	Orientation	Elevation	Verification
57							
58							
59							
60							
61							
62							
63							
64							
65							
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Searcher-Participant Log (12)

Searcher--Participant Log

Print as many copies as needed.

1. Date	2. Location			3. Page	of	
Printed Name	Organization	SAR Qualification	Emergency Contact	Arrival Date/Time	Available Until?	Departure Date/Time

Team Sign-Up (13)

Team Sign-Up			1. Location	2. Experiment Date	3. Projected # searchers
4. Sunrise	5. Sunset		6. Estimated Avg Completion hours		7. Actual Avg

The team sign-up log is used to schedule the departure times for teams (searcher and data logger) participating in the experiment. All attempts should be made to assign teams in the clock-wise direction before sending teams counter-clockwise. Searchers cannot function as a searcher twice. However, they can serve as a searcher then a data logger. Data loggers may be reassigned as often as needed.

Team		Clock-wise		Counter-Clockwise	
Number	Time	Searcher	Data Logger	Searcher	Data Logger
	7:00				
	7:15				
	7:30				
	7:45				
	8:00				
	8:15				
	8:30				
	8:45				
	9:00				
	9:15				
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	17:00				
	17:15				
	17:30				
	17:45				
	18:00				

Subject Information Sheet (14)

Subject Information Sheet	**1. Location**	**2. Date**	**3. Time**
4. Subject Name Thomas Tema		**5. Gender** Male	**6. Age** 35
7. Name to Call Tom (N/A)	**8. Expected Response** None, subject 100% deaf		

9. Subject's Plans or Intent
Subject departed campground to scout out survey locations. Last seen at the campground last night. Reported missing by employer early this morning. Should have been out of the field early.

10. Physical Description

Height:	5'10"	**Weight**	175 lbs
Race	White	**Build**	Avg
Eyes	Hazel	**Hair**	Blond
Complexion	Good	**Facial hair**	Clean

11. Photo Changes: Clean-shaven when last seen. **Date Taken** 2002

12. Clothing Description
Dark blue pants, dark blue workshirt. May have white overalls with him. May have orange survey vest. Black boots. May have small backpack with assorted gear.

13. Footwear/Track Description
Vibram sole.

14. Incident Summary/Other Pertinent Information
Subject parked at campground. Is a contractor to do survey work. Should have returned Friday night. Contractor informed SAR of overdue report this morning. Subject is an insulin dependent diabetic and is totally deaf.

Subj. Info. Sheet Worksheet 14 3/24/2006	**15. Prepared by**	**16. Date Prepared**

Task Assignment Form (15)

1. Resource Type:
2. Planning #
3. Priority:

☐ 4. Task Completed
☐ 5. Partial Completion
☐ 6. Urgent Follow-Up

Task Assignment Form	7. Task Number	8. Team Identifier	9. Resource Type	10. Task Map	11. Datum
			Ground		

ASSIGNMENT

12. Task Instructions

- Data loggers serves as team leader and will handle navigation, team control, and radio communications.
- Start task as indicated on map and follow pink flags data logger indicates.
- **Stay on track** marked by pink flags at all times.
- Proceed at a typical search speed for a sweep task. Data logger may ask you to speed up.
- Do NOT race through the course, Data logger may ask you to slow down.
- Upon spotting a search object; stop, point at the object, tell data logger what object is, and estimated range.
- Data loggers will give guidance to types of valid clues that need to be reported.
- Do **NOT** report objects over the radio!
- Talk to your data logger to a minimum.
- Data logger is responsible for recording all results.
- If you spot another team moving in the same direction as you, follow your data loggers instructions.
- Upon completing assigned task area return to base for debriefing.
- Do not share your results with anyone until the experiment has concluded.

13. Previous Search Effort in Area

Several teams have already walked the track today, do **not** record or report tracks.

14. Transportation to Area

15. Equipment

16. Briefing Checklist
- Expected time frame
- Teams nearby
- Encounter with team
- Terrain/Hazards
- Weather/Safety
- Subject Information
- Rescue/Medical Plan

TEAM

17. Role	Name	Agency	Medical Certification
Data Logger			
Searcher			

COMMO

18. Pertinent Phone Numbers

Base:
Base Cell:
Team Cell #1:
Team Cell #2:

19. Communications Instructions

Report to base when starting task, at each 500 m waypoint, and when finishing task. Do **NOT** radio in clues or search objects.

20. Function	Frequency	Channel Description	Comments
Tactical I (Team - Base)			
Tactical II			
Logistics			
Command			

21. Notes/Safety Message

Task Assignment Form - Worksheet 15	22. Prepared by:	23. Briefed by:	24. Time out:
3/24/06			

Data Logger Briefing (16)

General Briefing Data Logger	1. Location	2. Date

3. Task Instructions

Data Logger serves as team leader and will handle navigation, team control, and radio communications.
Start task as indicated on map, follow flags. Yellow flags serve as start, waypoint, and finish indicators.
Lime-green flags mark every 25 meters. These will help determine your location when a clue is reported.
Hot pink flags assist with navigation and help to mark the course. STAY ON THE TRACK
Stay behind the searcher.
Record the starting time on your detection log. If possible radio in your starting and finishing time.
Your searcher should be encouraged to move at a typical sweep task speed. Not racing or moving too slow.
Your team should reach the 100 meter mark (yellow flag) within 6 minutes. If longer, ask your searcher to increase speed. If you reach the 100 meter mark quicker than 2 minutes ask your searcher to slow down.
Talk to the searcher to a minimum.
GIVE NO CLUES or HINTS, to the number of clues, types of clues. You may encourage searcher to avoid reporting common trash or items not related to the search scenario.
Do NOT discuss what you found or didn't find if you covered the course as a searcher.
Do NOT report any clues over the radio.
Do NOT allow the searcher to leave the search track. If they think they spot a search object record the sighting.
Do NOT record any tracks or signs.
Upon searcher spotting an object, record the sighting on the detection log (as instructed).
Record the time you pass a yellow flag (placed every 500 meters or at other waypoints).
PASSING RULES: 1) The first time you spot a team in front, slow down or wait 5 minutes (unless the team has stopped; then pass). 2) If you catch up to the team again, passing is allowed. 3) Initiating passing should be done when within voice contact. 4) Announce you are going to pass, try to ensure team is not in process of recording a sighting. 5) Do not allow searchers to discuss clues spotted. 6) If your team was passed, make sure your searcher stays focused on searching. 7.) USE COMMON SENSE,
The goal is to avoid one searcher watching another searcher making a sighting.
Be sure to report back to base for debriefing and collection of your forms.

16. Briefing Checklist
- Expected time frame
- Teams nearby
- Encounter with team
- Terrain/Hazards
- Weather/Safety
- Subject Information
- Rescue/Medical Plan

14. Transportation to Area	15. Equipment
	Data logging record sheet

Communication Plan

17. Pertinent Phone Numbers	18. Communications Instructions
Base:	Report to base when starting task, at each 500 m waypoint and when finishing task. Do **NOT** radio in clues or search objects.
Base Cell:	
Team Cell #1:	
Team Cell #2:	

19. Function	Frequency	Channel Description	Comments
Tactical I (Team - Base)			
Tactical II			
Logistics			
Command			

20. Notes/Safety Message

Data Logger Worksheet 16 3/24/06	21. Prepared by:	22. Briefed by:	23. Time out:

Team Tracking Log (17)

Team Tracking Log

1. Location
2. Date
3. Page ________ of ________ Pages

Task # Number	Team Identifier	Searcher Name	Data Logger Name	Team Cell Phone Number	Clock or Counterclock wise	Time Out*	Time Start*	Time Done*	Time Back*

* Local Time, 24-hour format. Once a team has returned to base, highlight the entire row.

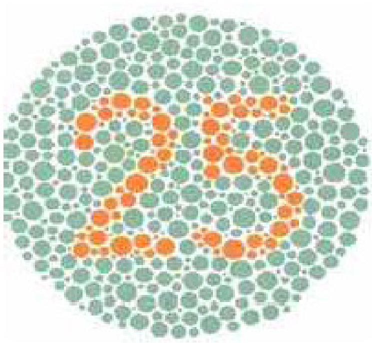
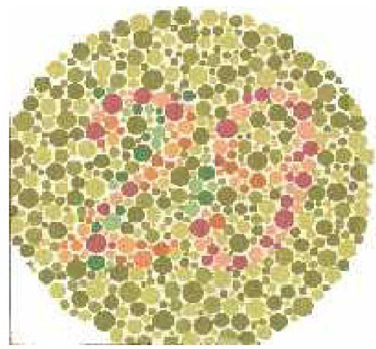
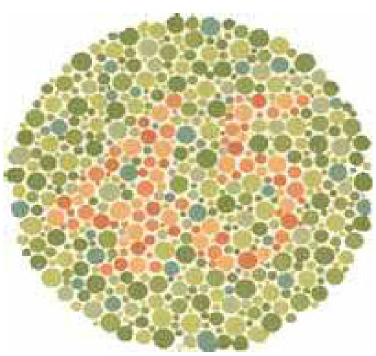
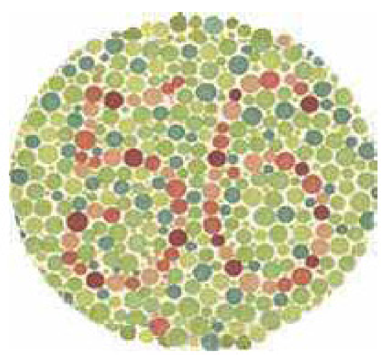
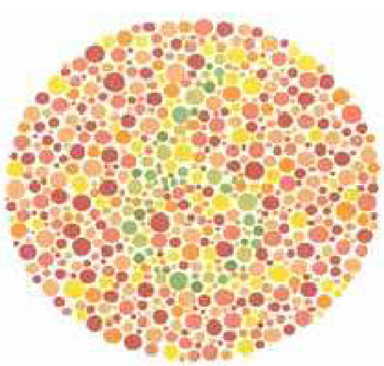
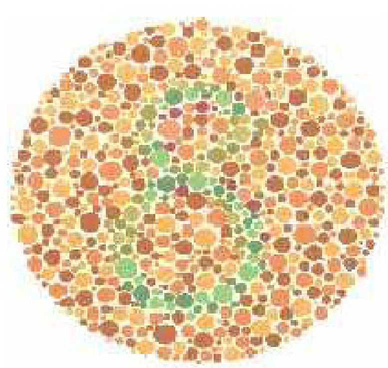
Vision Tests (18)

Two vision tests will be given to search participants. Visual acuity (20/20) and the Ishihara test for color blindness. The tests should be given by the experiment staff as part of the check-in procedure. The results will be recorded on the Searcher Profile (Worksheet # 19).

Ishihara Test for Color Blindness

Instructions: Print out this page on a color printer. Place under a clear plastic sheet for protection.

Instructions for Searchers:
Please record the numbers you see revealed in the patterns of notes below on your Searcher Profile (Worksheet # 19) under the color blindness test.

A 	B 
C 	D 
E 	F 

Vision Acuity Test

Searcher Profile (19)

Searcher Profile	1. Name	2. SAR Organization	3.SAR Sign-In Level	4. Date/Time
FOR OFFICE USE **Searcher Number**	**INSTRUCTIONS:** Please complete all the requested information in section A prior to departing on your search task. Your name will not be entered into the final database. The research staff will assist you in completing section B (measurements). After you return from you task, please complete section C (Debriefing). Thank-You!			

Section A - Searcher Demographics

6. Age	7. Gender ☐ Male ☐ Female	9. # of years in SAR	10. # of Searches	11. # of Search in Field	12. Regular Occupation

13. Primary SAR Specialty (Check only one)

				☐ **None**
☐ Ground Searcher	☐ Bike SAR	☐ Helicopter pilot	☐ Ski Patrol	☐ Mountain rescue
☐ Tracking	☐ ATV SAR	☐ Fixed-wing pilot	☐ Swiftwater rescue	☐ USAR
☐ Dog Handler	☐ Snowmobile SAR	☐ Maritime SAR	☐ Cave rescue	☐ SAR management
☐ Mounted (horse)	☐ 4 x 4 SAR	☐ Fire/EMS	☐ Tech. Rescue	☐ Other:________

14. SAR Certifications (Please list)

Section B - Physical Characteristics

15. Height w/ boots	16. Wear Glasses? ☐ No ☐ Yes ☐ Sometimes	17. Eyewear in field? ☐ No ☐ Yes	18. Visual Acuity	Uncorrected	Corrected
			Right		
			Left		

19. Colorblind? ☐ Yes ☐ No	20. Using the supplied Ishihara colorblindness chart, please record the numbers revealed by the pattern of dots. Leave blank if no numbers seen.	A.	B.
		C.	D.
		E.	F.

Section C - Debriefing

21. Hours on Task	22. Morale? ☐ High ☐ Medium ☐ Low	23. Fatigue ☐ Alert ☐ Medium ☐ Drowsy	24. Estimated POD

	Object	Est. POD
Object 1	Adult High-Visibility	
Object 2	Adult Low-Visibility	
Object 3	Child Medium-Visibility	
Object 4	Clue High-Visibility	

25. Temp	26. Wind Speed	27. Cloud Cover (%)	28. Lux
29. Light (direct, indirect, overcast, darkday, twilight, night)	30. Precipitation (type and intensity)	31. Meteorological Visibility	
32.Problems encountered on Task/Suggestions/Comments	33. Optional Question	34.Optional Question 2	
35. Are you willing to serve as a data logger today?	36. E-mail address (optional - only if you wish to be contacted about results)		

Section D - Data Loggers Comments

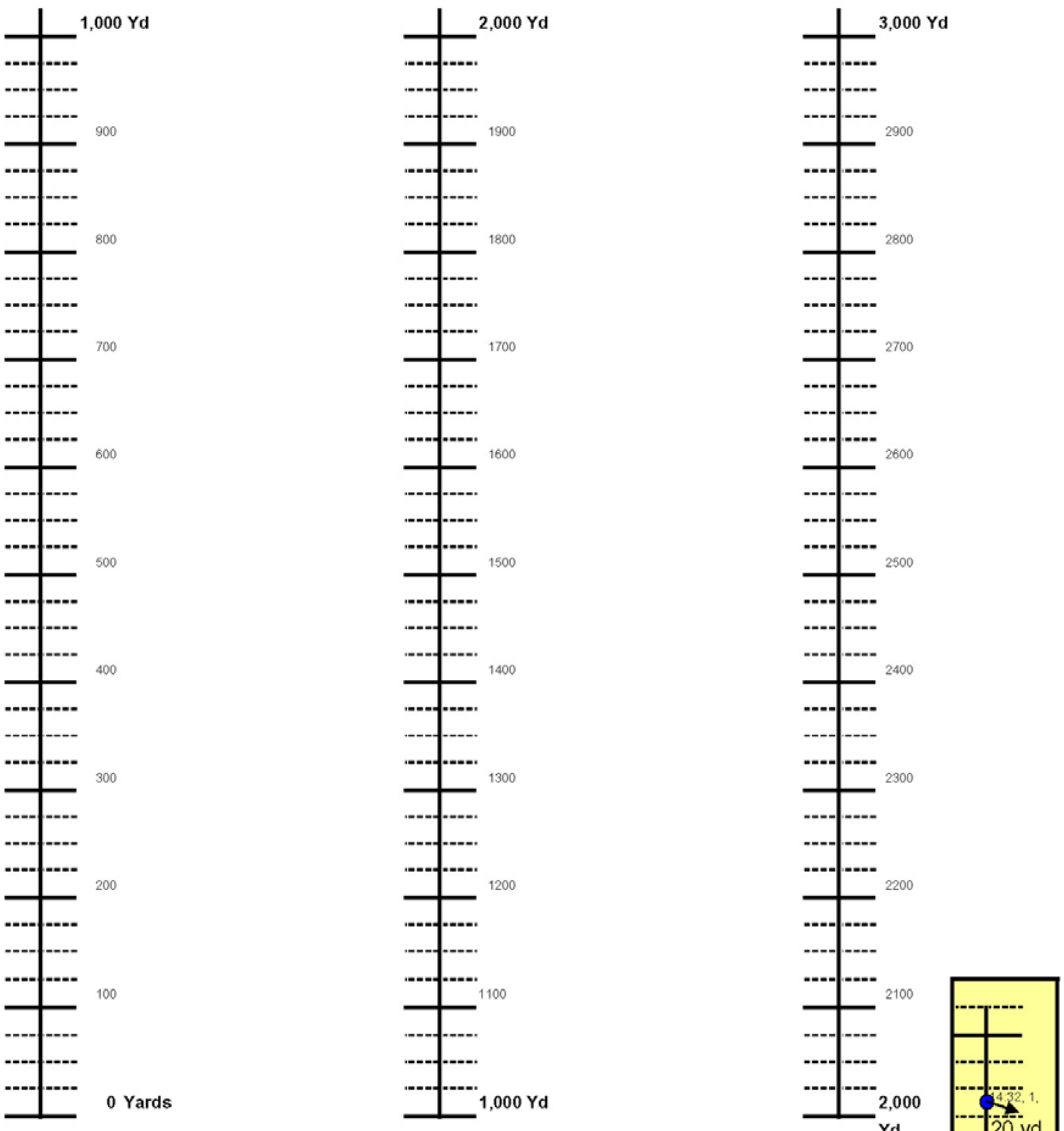
Searcher	**Never**	**Once**	**Seldom**	**Frequently**	Data logger comments, suggestions, problems encountered
Looked backwards					
Looked sideways					
Stopped and searched					
Scanned systematically					
Talked					
Wore hat/hood					

Searcher Profile Worksheet # 19 3/25/2006	37. Debriefed by	38. Time	**PLEASE MAKE SURE THIS FORM TURNED INTO MISSION BASE STAFF! THANK-YOU**

Detection Log (20)

Detection Log	1. Searcher's Name	2. Data Logger's Name	3. Location	4. Date
5. Direction of Movement	☐ Clockwise (#s increasing)	☐ Counterclockwise		
6. Search Object Type 1	7. Search Object Type 2	8. Search Object Type 3	9. Search Object Type 4	

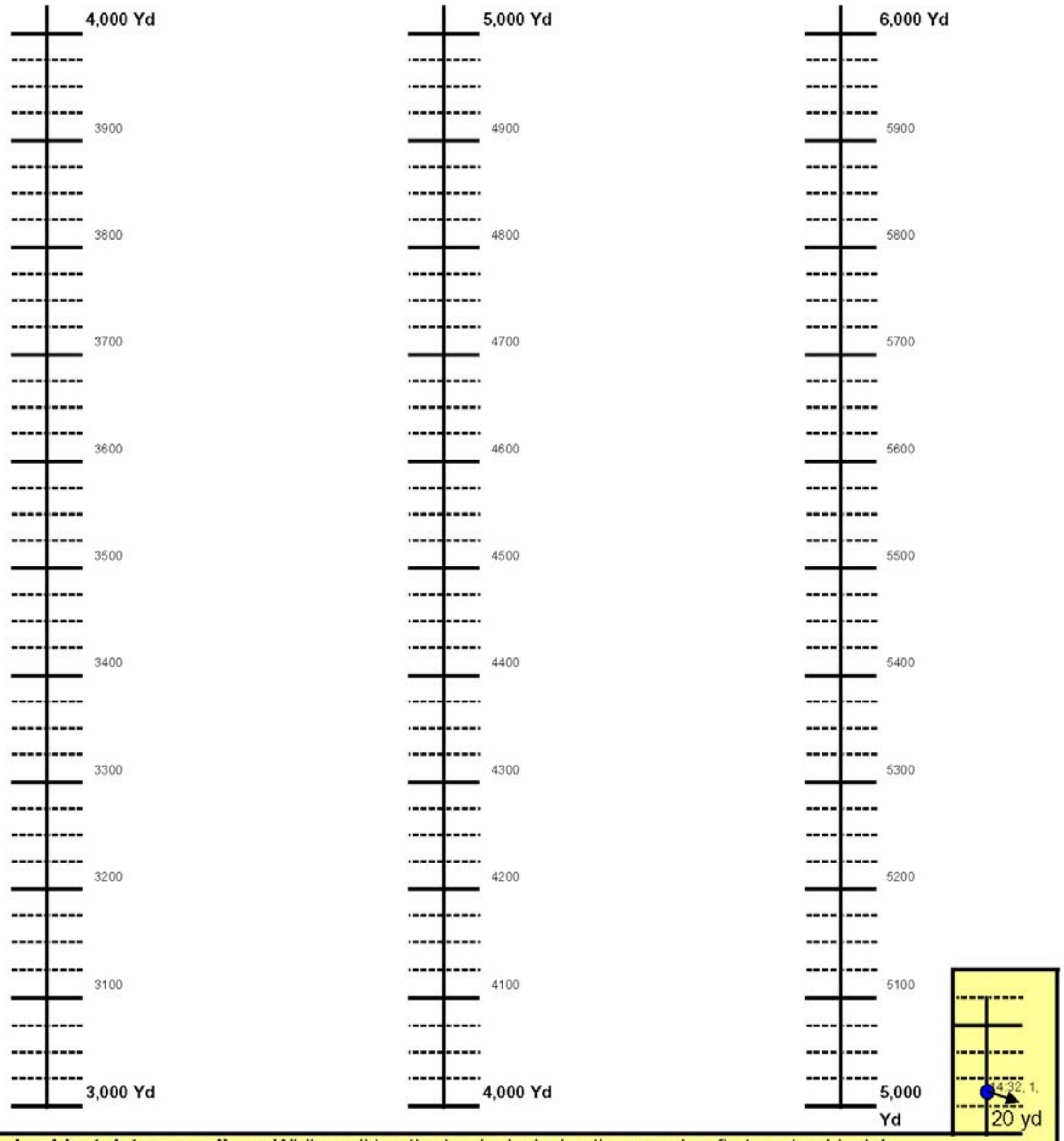
Instructions: For each sighting the searcher makes, the data logger should record the following information: The team's location by placing a dot on the track using the wayflags, the time of the sighting, what the searcher sees, the estimated range of the object, and an arrow that gives the relative direction of the object.
All sightings should be recorded even if not matching to a known object. An example sighting record is provided below. Record time at start, finish, and waypoints specified.



Example object data recording: While walking the track clockwise the searcher first spots object 1 at 14:32 halfway between flags 325 and 350, 20 meters (or yards) away at 4 o'clock.

Detection Log (Cnt'd)	1. Searcher's Name	2. Data Logger's Name	3. Location	4. Date
5. Direction of Movement	☐ Clockwise (#s increasing)	☐ Counterclockwise		
6. Search Object Type 1	7. Search Object Type 2	8. Search Object Type 3	9. Search Object Type 4	

Instructions: For each sighting the searcher makes, the data logger should record the following information: The team's location by placing a dot on the track using the wayflags, the time of the sighting, what the searcher sees, the estimated range of the object, and an arrow that gives the relative direction of the object.
All sightings should be recorded even if not matching to a known object. An example sighting record is provided below. Record time at start, finish, and waypoints specified.



Example object data recording: While walking the track clockwise the searcher first spots object 1 at 14:32 halfway between flags 325 and 350, 20 meters (or yards) away at 4 o'clock.

Detection Log Scoring Template (21)

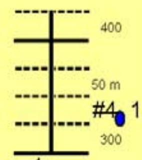
Detection Log Scoring Template

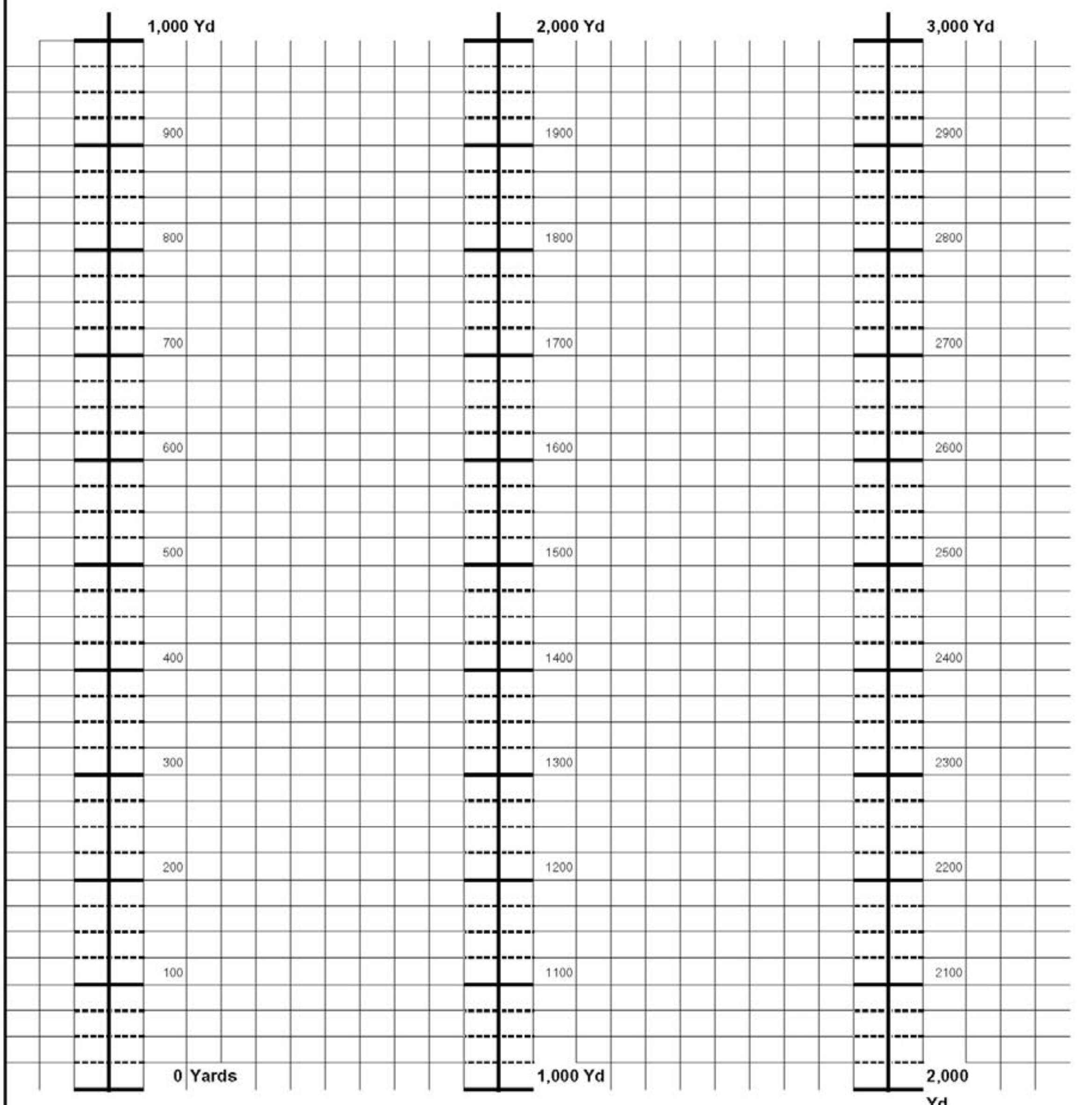
1. Location			
6. Search Object Type 1	7. Search Object Type 2	8. Search Object Type 3	9. Search Object Type 4

Instructions: Print out a copy of this template. Then, using Search Object Placement and Chart (Worksheet # 10) plot the known location of each search object. Plot track distance, lateral range, right/left, and search object type. Indicate the search object type by 1, 2, 3 or 4. Copy/print the template onto acetate. Place the acetate over each searcher's Detection Log (Worksheet # 20) and determine for each search object if a valid detection occurred. For each search object, record on the Detection Scoring (Worksheet # 22) a "1" if a valid detection was made or a "0" if the it was missed.

Example

Object #4
TL=327
LR=50
Right
Object Type=1



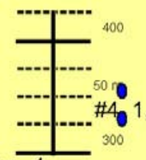


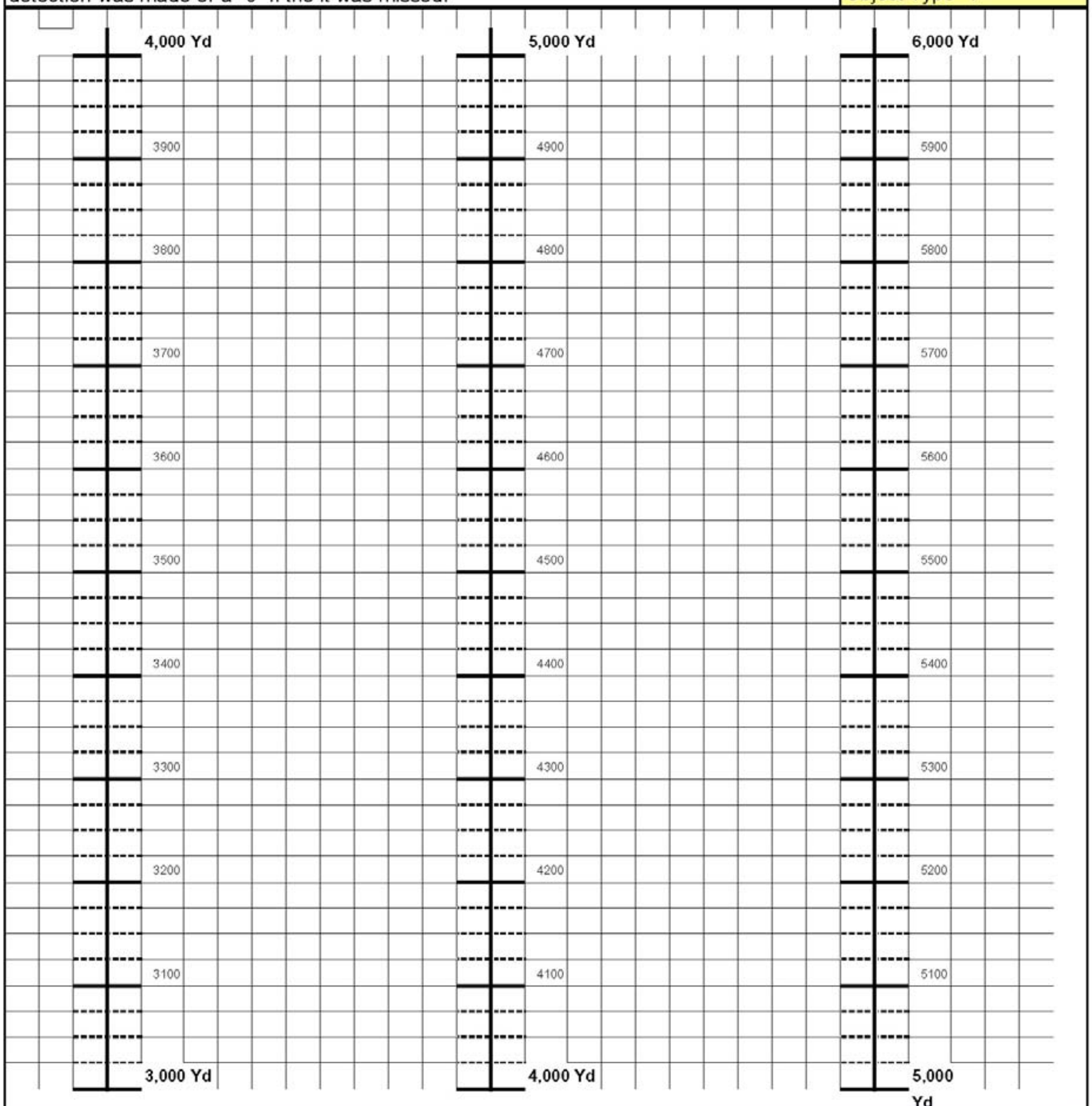
Detection Log Scoring Template (Cnt'd)		1. Location	
6. Search Object Type 1	7. Search Object Type 2	8. Search Object Type 3	9. Search Object Type 4

Instructions: Print out a copy of this template. Then, using Object Placement and Chart (Worksheet # 10) plot the known location of each search object. Plot the track distance, lateral range, right/left, and search object type. Indicate the search object type by 1, 2, 3 or 4. Copy/print the template onto acetate. Place the acetate over each searcher's Detection Log (Worksheet # 20) and determine for each search object if a valid detection occurred. For each search object, record on the Detection Scoring (Worksheet # 22) a "1" if a valid detection was made or a "0" if the it was missed.

Example

Object #4
TL=327
LR=50
Right
Object Type=1





Detection Scoring (22)

Detection Scoring	1. Searcher's Name	2. Searcher Number	3. Data Logger's Name	4. Date
5. Search Object 1	6. Search Object 2	7. Search Object 3	8. Search Object 3	7. Location

Instructions: Using the searcher's **Detection Log** (Worksheet # 20) and the **Detection Template** (Worksheet # 21) record below if a valid detection occurred. Record a zero "0" in the appropriate search object column if the search object was missed. If changes were made after Object Placement and Chart (Worksheet # 10) was printed and during search object set-up, make changes by hand on this form. Record a one "1" in the appropriate search object column if that search object was detected. Leave the other search object column blank. Staple together the following forms; the Searcher Profile (Worksheet # 19), the Detection Log (Worksheet # 20), and the scored Detection Scoring (Worksheet # 22). The results from this paper form will be inputted into the Data Input Object 1, 2, 3 and 4 (Worksheets # 23, 24, and 25) in order to determine the Sweep Width value for each object.

Location Number	Search Object 1	Detections Object 2	Detections Object 3	Detections Object 4
1				
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3				
4				
5				
6				
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Location Number	Detections Object 1	Detections Object 2	Detections Object 3	Detections Object 4
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99				
100				

Detection Scoring (22)

Page 2 of 2

Location Number	Search Object 1	Detections Object 2	Detections Object 3	Detections Object 4
101				
102				
103				
104				
105				

Location Number	Detections Object 1	Detections Object 2	Detections Object 3	Detections Object 4
106				
107				
108				
109				
110				

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Appendix G. Scientific Background

B.O. Koopman (1946, 1980) established the basis for a rigorous study of search theory and practice with his pioneering work for the U. S. Navy during WWII. Prior to his work there was no published scientific literature on search theory. Koopman was a member of the Navy's *Operations Evaluation Group* (OEG). An important characteristic of this group was that its members were required to spend several years in the field working directly with operations personnel. All work produced by this group had to be both scientifically sound and practical enough for operational use by Navy personnel without requiring them to have any special scientific training. It also had to show practical results. The work initially done by the OEG was instrumental in winning the Battle of the Atlantic against the German U-boats. Although this kind of application may seem far removed from searching for lost persons on land, the basic theory of search Koopman established applies to all types of searching. An essential part of Koopman's work was developing the concept of effective search (or sweep) width—an objective numeric measure of how easy or hard it is for a given sensor to detect a given object in a given operating environment. Whenever the basic theory has been applied, substantial improvements in search success rates and reductions in the average times and resources required to achieve success have been realized. It is Koopman's work that will form the basis for the effective sweep width estimation technique developed in this paper. For a detailed yet readable elaboration on the development of the theory see Frost (1999a, 1999b, 1999c, & 1999d).

Although search theory was applied to military SAR operations during and after WWII, the U. S. Coast Guard provided the first comprehensive application to civil SAR in the 1950s. The methodology was incorporated into the first edition of the *National Search and Rescue Manual* in 1959 and it quickly gained acceptance by maritime SAR agencies worldwide. It has remained in global use ever since. Various practical improvements and modifications to search planning techniques and data have been made over the years, but the application of the underlying theory remains unchanged, as shown in the *International Aeronautical and Maritime Search and Rescue Manual (IAMSAR Manual, 1999)* published jointly by the *International Maritime Organization* and the *International Civil Aviation Organization* and recognized globally as the standard text on aeronautical and maritime SAR operations and methods.

"Detectability"

One of the weaknesses of the original implementation of search theory by the U. S. Coast Guard was that the "detectability" data available until the late 1970s reflected primarily maximum detection ranges for maritime SAR objects such as life rafts. There is only a very loose relationship between maximum detection range and the measure of detectability known as the effective search (or sweep) width. In other words, the data originally available were not a very good measure of detectability and they tended to be optimistic, producing effective sweep width estimates, and POD values, that were larger than they should have been.

In 1978 the U.S. Coast Guard Research & Development Center began an extensive data collection project to measure the effective sweep widths for a wide variety of realistic SAR objects, under realistic environmental conditions using actual Coast Guard crews and Search and Rescue Units (SRUs). The experiments were conducted over a period of more than twenty years. The data collected and the lessons learned during this series of experiments formed the basis for the *National SAR Manual* and *IAMSAR Manual* sweep width tables and search planning guidance, including POD estimation. In developing the methodology for the estimation of effective sweep width for land search we have drawn on the experience of the maritime SAR community while acknowledging the considerable differences in search techniques and environments found on land. The common link between evaluating detectability in the maritime and land environments is that each searcher/search object interaction is resolved as either a detection or a non-detection.

Lateral Range

The method for estimating effective sweep width uses the concept of a "lateral range curve". This concept, introduced by Koopman (1946), has a number of properties that recommend it for sweep width estimation. Lateral range refers to the perpendicular distance an object is to the left or right of the searcher's track where the track passes the object. Thus it represents the distance from the searcher to the object at the closest point of approach (CPA). A lateral range curve is a plot of the probability of detecting the object on a single pass as a function of the object's lateral range from the searcher's track, i.e., as a function of how closely the searcher approaches the object. Figure 2-1 shows a hypothetical relationship between POD on a single pass and an arbitrary scale of distances to the left (negative) and right (positive) of the searcher's track.

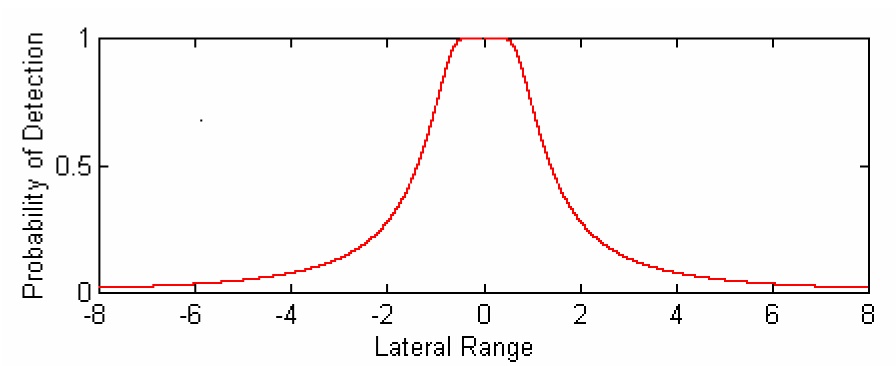


Figure G-1. A lateral range curve (a.k.a. detection profile).

Koopman (1946) derived this particular relationship from the physical geometry of an aircraft flying over the ocean in search of an object on the surface. Negative values are distances to the left of the searcher's track while positive values are distances to the right of the searcher's track.

Visual search (as anyone looking for their keys knows) is highly dependent on distance. This is largely due to the simple physics of the eye, the closer the object the greater the visual angle. The visual angle versus distance for the two different size search objects used in the experiments (adult and glove) is shown in Figure G-2. It can be noted how closely the simple physics of the eye matches the lateral range curve (detection profile) shown in Fig. G-

1. At first one would think that the important measure in any detection is the actual range at which the detection takes place. This begs the question of what range should be assigned to a non-detection when the searcher passes the object without detecting it. The answer is that the non-detection may take place at all ranges down to and including the closest point of approach (CPA) or the "lateral range" value. It is also true that an object may be detectable for some time before it actually ***is*** detected. That is, detections may occur at any distance between the point where the searcher first gets close enough to make detection possible down to the CPA and then beyond to where detection is no longer possible. Therefore, both detection and non-detection events will be referenced to the lateral range or off-track distance.

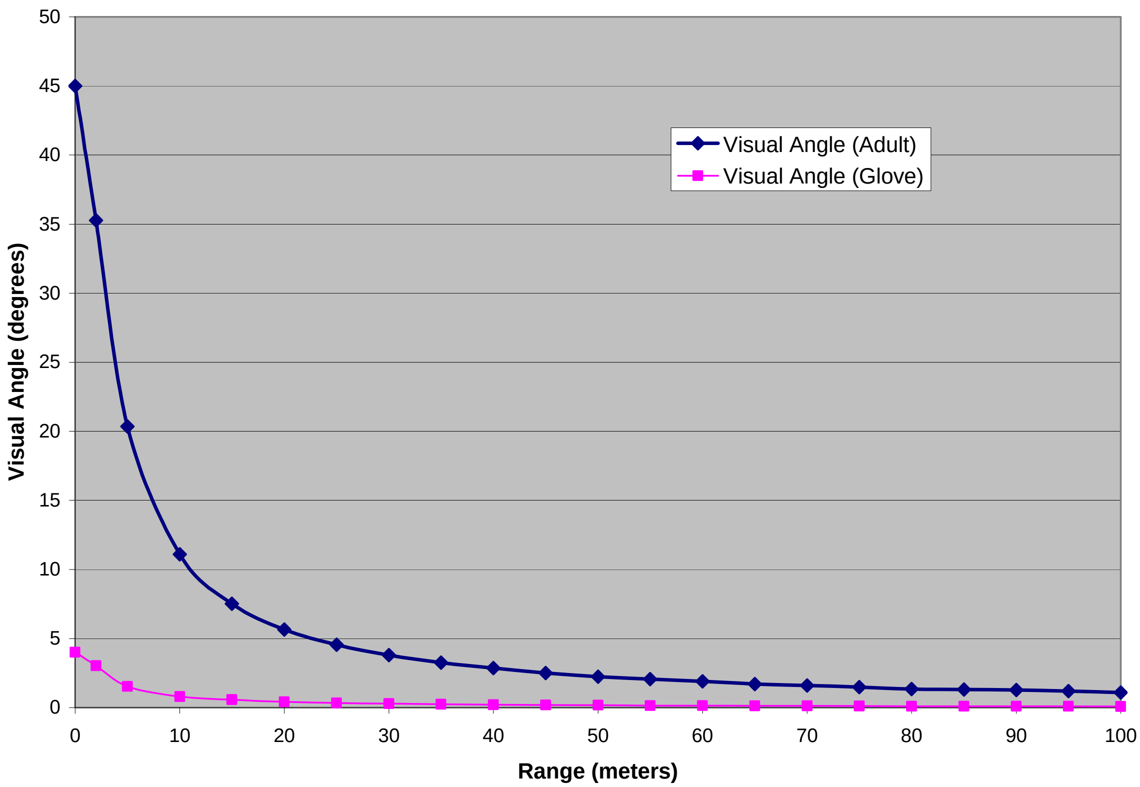


Figure G-2. Angle versus range of adult (body) and glove (clue).

The lateral range method also functions as a natural integrator of the effects various factors have on the detection process during the experiment. Even in a fairly constant environment, many factors may affect detection. The searcher may look elsewhere just at the time the object appears in an opening in the vegetation; wind or rain may affect visibility at a particular point; one searcher may have better scanning technique or eyesight than another; or the object may require several glimpses to register on the consciousness of the searcher, especially if it has a low contrast with its surroundings. For each searcher participating in a detection experiment, the lateral range concept makes detection data collection a matter of answering a simple question: "Did the searcher detect the object as he/she passed it or did the searcher not detect it?"

Effective Sweep Width

S*weep width* is one of the central concepts of search theory and its application to SAR. The term *sweep width* has a specific mathematical definition different from what one might infer from the usual meanings of its component words. Therefore, we should discuss the term at least briefly before proceeding further and provide at least one or more informal definitions. References to more complete and mathematically rigorous discussions will be provided.

Sweep width is a single number characterizing the average ability of a given sensor to detect a particular search object under a specific set of environmental conditions. Thus each combination of sensor, search object, and set of environmental conditions will have a particular associated sweep width. In the vernacular, sweep width might be called a measure of "raw detection power." Loosely paraphrasing Koopman (1980), sweep width may be described as follows:

Consider a sensor moving with constant velocity through (or over) a swarm of uniformly distributed, identical, stationary search objects under constant environmental conditions. If the average number of objects detected per unit time is divided by the object density (average number of objects per unit area), the resulting value is called the *effective search or sweep rate*. It is easy to see that the effective sweep rate has dimensions of area over time (e.g. square miles per hour). Dividing the effective sweep rate by the speed of the sensor gives the *effective search or sweep width*, which has units of length.

Notice that the above description does not imply that every object in the "swept area" is detected. Indeed, the meaning of "swept area" itself is not clear. To clarify how the term *sweep width* got its name, we will give an alternative description (also loosely derived from Koopman, 1980):

Consider an omnidirectional sensor that is "perfect" (i.e. 100% effective) within some definite range and completely ineffective beyond that range. That is, detection is guaranteed for any object the sensor approaches more closely than the definite detection range, and the sensor never detects any object beyond that range. This idea is analogous to setting a lawn mower's blade to a height of zero and then pushing it into tall grass. The lawn mower would leave behind it a swath of bare earth having a definite width (twice the definite detection range), while blades of grass outside this width would be untouched. Inserting this particular sensor into the previous description, it is easily seen that in this special case (and this special case alone), the sweep width is literally the width of the swept area where the detections took place, i.e. twice the definite detection range. The concept is generalized by defining the *effective sweep width* of any sensor as equal to the sweep width of a definite range sensor that detects the same number of objects per unit time as the given sensor does under identical circumstances (i.e., same sensor speed, same object density, same environmental conditions). Generally the word *effective* is dropped, shortening the term to just *sweep width*. This is sometimes a source of confusion to new students of search theory and also to search planners in the field.

We see that in only one situation, namely definite range detection, does the sweep width actually correspond to a physical, geometric width measurement. Otherwise, it is a more abstract concept, but nevertheless one of great value and utility on both the theoretical and operational fronts. Additional treatments of the sweep width concept, some with illustrations, may be found in Koopman (1980), Stone (1989), and Frost (1998c, 1999a).

Unfortunately, sweep width cannot be measured directly for cases other than definite range detection. This is one reason why it is difficult to explain. Another reason is the ease with which the term "sweep width" is confused with other, sometimes similar, terms that have quite different meanings and uses. We will now rectify this problem by giving several different, but equivalent, descriptions of what sweep width represents.

For all of the following descriptions, assume that search objects are uniformly, but randomly, spread over an area. A uniform random distribution means that the search object locations occur at random so their positions cannot be predicted, but the number of objects per unit of area is about the same everywhere. Also assume that the area covered with objects is very large compared to the maximum detection range.

Suppose an experiment was done where every searcher detected every object within a given lateral range, say 10 meters either side of the searcher's track, and detected no objects outside that range. That is, the searchers were 100% effective within 10 meters on either side of their track, and completely ineffective for objects farther from the searcher's track. This would constitute a "clean sweep" of a swath 20 meters wide with no detections outside that swath. The effective sweep width in this case would be 20 meters. In this "ideal" but unrealistic example, the effective sweep width is the same as the width of the swath where objects were detected.

Now suppose another experiment is done in another venue using the same number of objects per unit of area. Further suppose that the searchers in this experiment find objects that are up to 20 meters either side of their tracks, but they detect, on average, only half the objects located in that swath of 40 meters. Note that there will be twice as many objects in a 40 meters swath as in a 20 meters swath of the same length. Therefore, even though the searchers detect only half of those present in the 40 meter swath, they will detect just as many objects in one pass as the searchers in the previous experiment did. In this sense the two groups of searchers performed equivalently despite any differences in terrain, vegetation, searcher training, etc. So, for purposes of estimating how many objects will be detected in one pass, we would say the *effective sweep width* in both cases was 20 meters. That is, both groups of searchers detected the same number of objects as lay in a swath 20 meters wide even though only the first group did this in a literal sense.

This illustrates the difference between effective sweep width and maximum detection range. While it is possible to say that the width of the swath where searchers *can* detect objects will normally be about twice the maximum detection range, there is no way to predict from that information alone how many of the objects present in that swath *will* be detected, even if the number of objects present per unit of area is known. The effective sweep width, on the other hand, does allow us to estimate how many detections we should expect provided we also know the number of objects present per unit of area. Simply multiply the effective sweep width by the length of the searcher's track to get the area effectively swept then multiply this value by the number of objects per unit of area to get the number of detections that should be expected. Note that this value does not depend in any way on the maximum detection range and there is no known mathematical relationship between the two. Having a maximum detection range in one situation that is twice that of another situation does *not* mean objects in the first situation are twice as detectable, on average, as objects in the second situation. In fact, it is actually possible that a small, high-contrast object might have a very large maximum detection range in a given environment under just the right circumstances but be less detectable on average in that environment than a larger object with less contrast and a smaller maximum detection range. Knowing the maximum detection range does not help with POD estimation. But, the results of this report suggest that extensive and repeated experimentation may discern a relationship between the average maximum detection range (AMDR) and effective sweep width for a specific environment. Also note that just as knowing the maximum detection range does not tell us the effective sweep width, knowing the effective sweep width provides no information about the maximum detection range. However, knowing the effective sweep width gives us a way to reliably estimate POD since it is a measure of expected detection performance.

The effective sweep width may be thought of as the width of the swath where the number of objects *NOT detected inside* the swath are equal to the number of objects that *ARE detected outside* the swath. That is, when one gets to the point where the number of objects missed within a certain distance either side of track (areas B above the curve in Figure G-3) equals the number that are detected at greater distances from the searcher's track (areas A below the curve in Figure G-3), then one has found the effective sweep width.

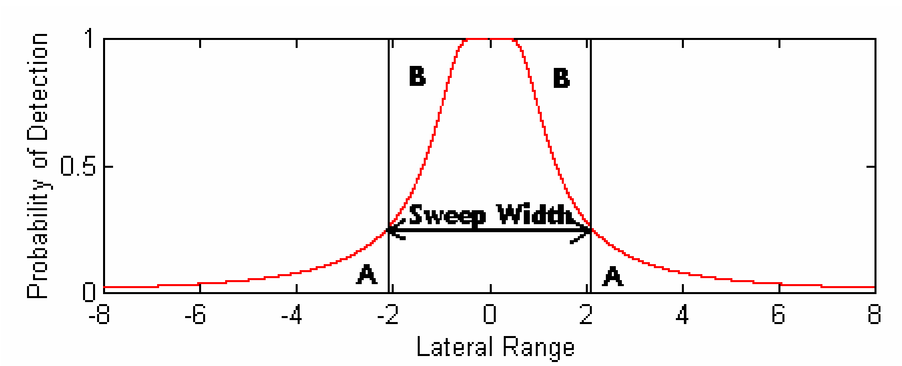


Figure G-3. A lateral range curve showing effective sweep width.
The number of missed detections (B) inside the effective sweep width
equals the number of detections (A) that occur outside the sweep width.

For the more mathematically inclined who are familiar with calculus, the effective sweep width is also numerically equal to the total area under the lateral range curve down to the horizontal axis of the graph. One way to estimate effective sweep width from experimental data is to analyze the detection/non-detection results to first get an estimate of the lateral range curve and then compute the area under that curve. However, this is significantly more difficult than some other data analysis methods.

Finally, if detection were perfect (100% POD) within a swath of width *W* and completely ineffective (0% POD) outside that swath, then the effective sweep width would be *W*. That is, if a "clean sweep" were possible with no detections outside the swept swath, the width of the swath would be, by definition, the effective sweep width. Sensors with perfect detection within some definite maximum detection range and perfectly sharp cutoffs at that definite maximum detection range do not exist. However, this perspective on sweep width reveals another important property: The effective sweep width can never exceed twice the maximum detection range. It is almost always considerably less than that value, but just how much less depends on the search situation and all the factors affecting detection. It is not possible to establish any general mathematical relationship between maximum detection range and effective sweep width.

Figures G-4, G-5, and G-6 below illustrate the concept of effective sweep width in another way. The black dots in Figure G-4 represent identical search objects that have been scattered randomly but approximately uniformly over an area. The distribution is "uniform" because in any reasonably large fraction of the area there are about the same number of objects as in any other fraction of the same size. The distribution is "random" because the exact location of each object was chosen at random to avoid producing either a predictable pattern or a bias favoring one portion of the area over another.

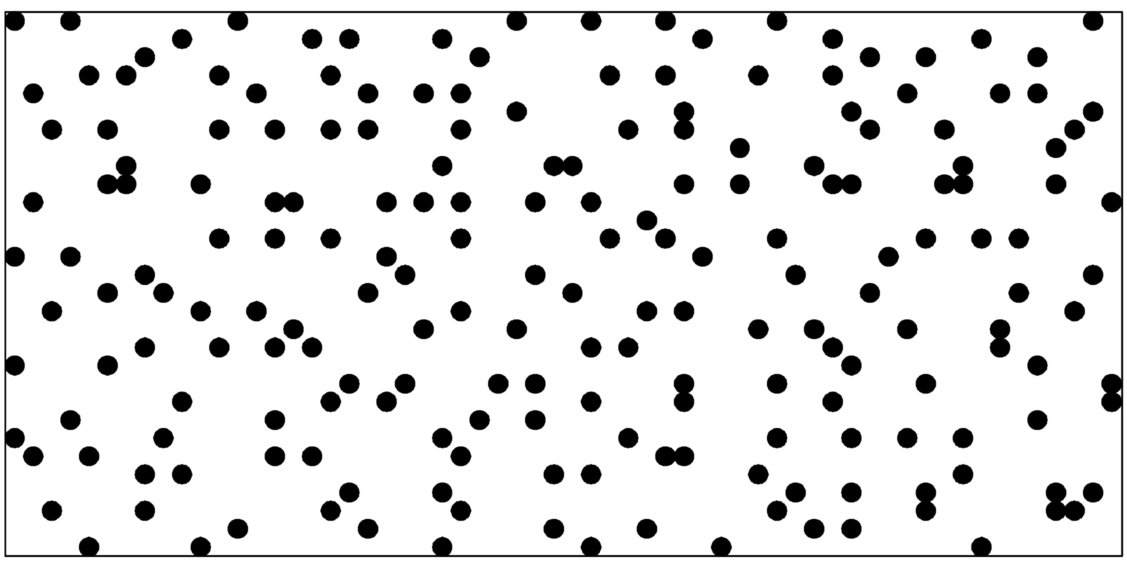


Figure G-4. A uniform random distribution of search objects.

Figure G-5 shows the effect of a "clean sweep" where all of the objects within a swath are detected and no objects outside the swath are sighted. In this case the effective sweep width is literally the width of the swept swath. A total of 40 objects lay within the sweep width and all 40 were detected, as indicated by the empty circles. A "clean sweep" where the searcher/sensor is 100% effective out to some definite range either side of the track is unrealistic, but it serves to illustrate the sweep width principle.

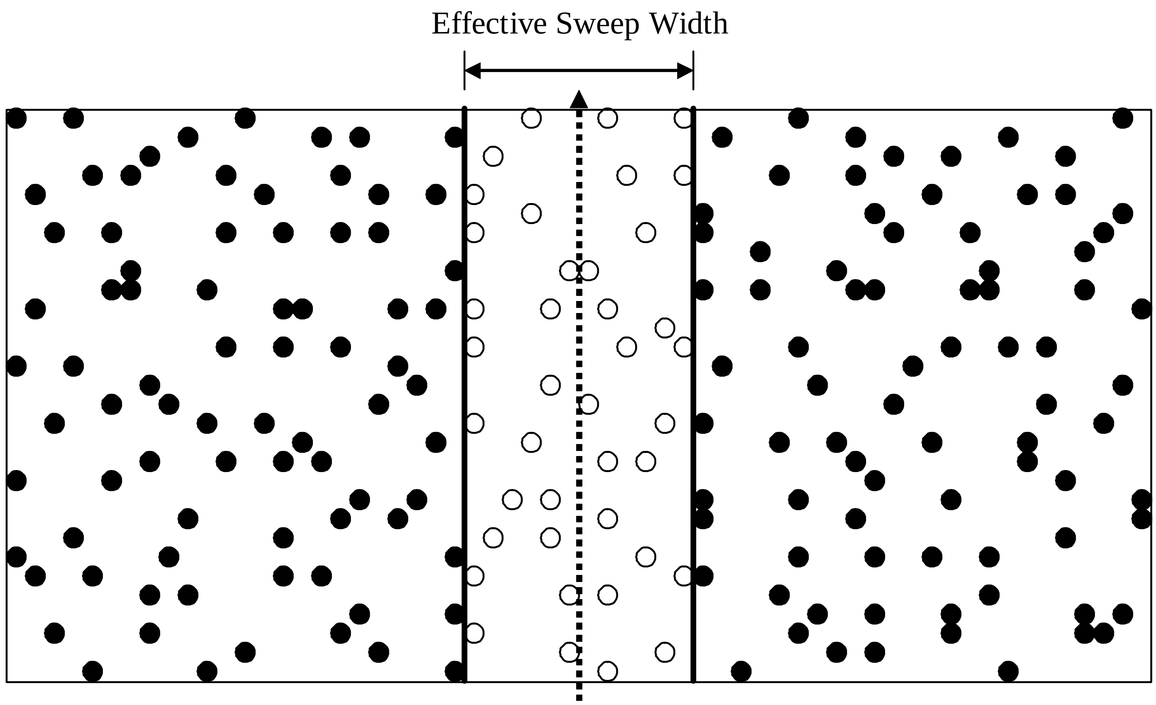


Figure G-5. Effective Sweep Width for a clean sweep.
Dotted line represents searcher's track. Number missed within sweep width = 0.
Number detected outside sweep width = 0.

Figure G-6 represents a more realistic situation where objects are detected over a wider swath, but not all the objects within that swath are found. In this case, the total number of objects detected was also 40 but instead of making a "clean sweep," the detections are more widely distributed. However, because in both cases 40 objects were detected over the same length of searcher track when the number of objects per unit of area was also the same, we say the *effective* sweep widths for both cases are equal.

Effective sweep width is a measure of detectability because, in a hypothetical situation where the average number of objects per unit of area is known, if we know the sweep width we can accurately predict how many of the objects will be found, on average, by single searchers on one pass through the area. As we will show later in this report, knowing the sweep width for a given combination of sensor (e.g., visual search), search object (e.g., a person) and environment (weather, terrain, vegetation, etc.) will allow us to accurately predict the probability of detection for any search conducted under those or similar conditions.

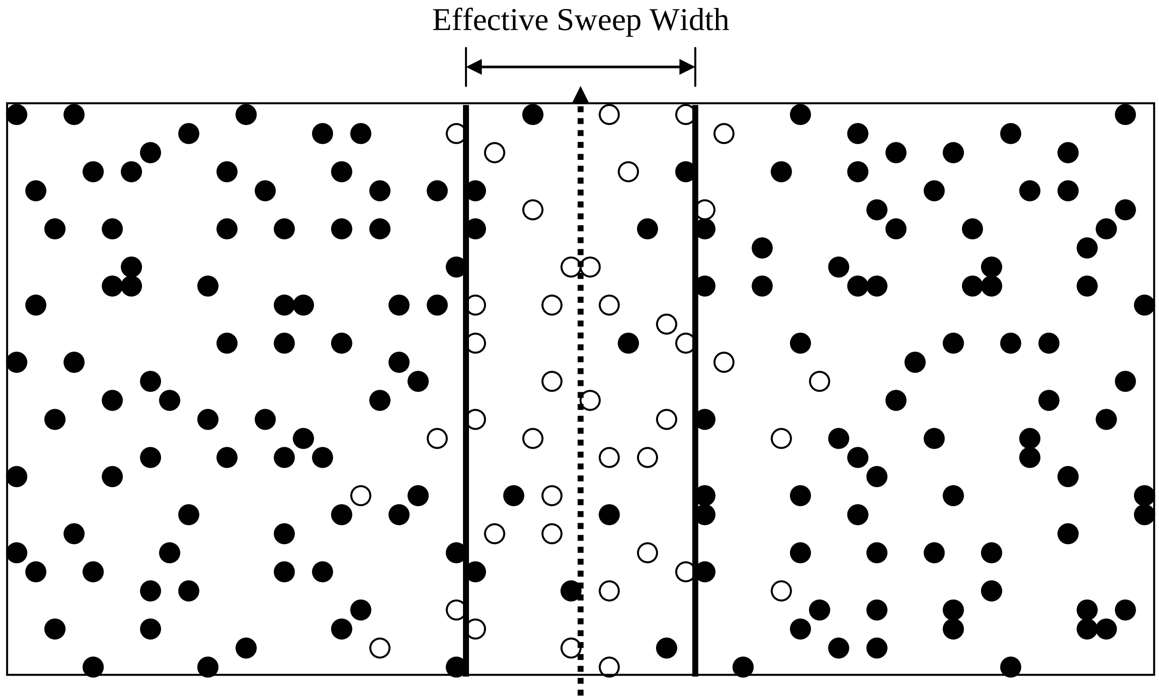


Figure G-6. Effective Sweep Width.
Dotted line represents searcher's track. Number missed within sweep width = 11.
Number detected outside sweep width = 11.

Figure G-6 also illustrates the property of effective sweep width where the number of undetected objects inside the swath equals the number of objects detected outside that swath.

To summarize: Sweep width is the metric used for estimating an object's detectability for a given search scenario. It is a single number having the dimensions of length. It may be derived from the lateral range curve that is produced from detection/non-detection data of an experiment that is appropriately designed and performed. It has the property that, on average, the number of search objects detected outside the effective sweep width is numerically equal to the number of search objects not detected within the effective sweep width (Figures G-3 and G-6). It is used together with the amount of effort expended in a given area (e.g., a search segment) and the size of the area to get an objective, reliable, and accurate estimate of POD.

As a practical matter, it is not possible to directly "measure" sweep width at the place and time of a search. It is also impossible to develop sweep width values for the infinitely many possible combinations of sensor, search object, and environmental conditions. The Coast Guard has addressed these problems by designing and conducting numerous experiments to gather empirical data from which operationally useful sweep width estimates may be inferred. The Coast Guard's Research and Development Center has been conducting such experiments for more than twenty years, identifying the significant variables affecting operational sweep widths in the marine environment and producing extensive sweep width tables indexed to these variables. These tables are published in the U. S. *National SAR Supplement* (National Search and Rescue Committee [NSARC], 2000) and in a simplified derivative form in the *International Aeronautical and Maritime Search and Rescue Manual* (ICAO/IMO, 1999a-c).

"Effort" and "Search Effort" (Area Effectively Swept)

Effort is a measure of resource expenditure and may be defined as the amount of distance covered by the searcher(s) in a search segment while searching. It could be measured in several ways, but the usual metric for search theory purposes is the distance a sensor platform travels while in the search segment. A search segment is defined as some bounded geographic area that a particular resource, such as a team of searchers, has been assigned to search. The distance a searcher covers while searching may be estimated by either estimating or recording the amounts of time spent searching (exclusive of rest or meal breaks, transit times to and from the assigned segment, etc.) and multiplying that value by the estimated average search speed using the familiar formula,

$$d = rt$$

for ***d***istance equals ***r***ate times ***t***ime. When a team of searchers is assigned a given segment, the total distance traveled by all members of the team will be needed. This value may be found by summing all the individual team member distances or, if all members moved at about the same speeds for about the same amounts of time while searching, then the distance covered by one searcher could be multiplied by the number of persons in the team to get the total distance covered in the segment. That is,

$$Effort = \sum_{i=1}^{n} d_i \text{ or } Effort = nd$$

where n is the number of searchers on the search team.

Search effort is a measure of how much "effective" searching is done by the sensor as it moves through the search area. *Search effort* is simply the product of the sweep width and the distance the sensor travels while in the search area or:

$$Area\ Effectively\ Swept = Effort \times Effective\ Sweep\ Width$$

It is easy to see that *search effort* has units of area. It is often called *area effectively swept*.

Coverage

Coverage (sometimes called *coverage factor*) is a relative measure of how thoroughly an area has been searched, or "covered." *Coverage* is defined as the ratio of the area effectively swept to the physical area of the segment that was searched:

$$Coverage = \frac{Area\ Effectively\ Swept}{Segment's\ Area}$$

Searching an area and achieving a *coverage* of 1.0 therefore means that the *area effectively swept* equals the area searched. Note that this does not necessarily mean that every piece of ground was scanned nor does it mean that the POD of a coverage 1.0 search is at or near 100%. Coverage is a measure of how "thoroughly" the segment was searched. The higher the coverage, the higher the POD will be. However, the relationship is not linear. That is, doubling the coverage does not double the POD. Figure G-7 (POD versus Coverage curve) shows the relationship between coverage and POD as derived by Koopman (1946, 1980) for situations where searchers do not move along a set of long, perfectly straight, parallel, equally spaced tracks but instead follow more irregular paths.

It is important to always remember that coverage and the corresponding level of effort are proportional. To double the coverage it is necessary to double the level of effort and doubling the level of effort doubles the coverage. In other words, although the relationship between POD and coverage is not linear, the relationship between coverage and effort is. This means, by extension, that the relationship between effort and POD is not linear, either. Doubling the effort assigned to a segment will not generally double the POD.

Since terrain and vegetation often prevent ground searchers from following a mathematically precise pattern of parallel tracks, and since ground searchers frequently alter their tracks to investigate possible sightings, look behind major obstructions, etc., the exponential detection function, as the curve in Figure 2-7 is called, seems to be the most appropriate for estimating ground search POD. This curve also works well when other "random" influences are present, such as uneven terrain and vegetation, even when the searcher tracks are perfectly straight, parallel, and equally spaced. The equation of this curve is

$$POD = 1 - e^{-Coverage}$$

where e is the base of the natural logarithms (approximately 2.718282). The function e^x or EXP is available with most handheld scientific calculators and electronic spreadsheet programs.

It can be seen that *coverage* is proportional to *search effort density*, the constant of proportionality being the *sweep width*. Therefore, any solution to the optimal search density problem is also a solution to the optimal coverage problem. In this sense, the two terms may be used interchangeably when discussing optimal search plans.

Probability of Detection (POD)

The probability of detection (POD) is defined as the *conditional* probability that the search object will be detected during a single sortie *if* the search object is present in the area searched during the sortie. Cumulative POD (POD_{cum}) is the cumulative probability of detecting the search object given that it was in the searched area on each of several successive searches of that area. Like coverage, it is a measure of how thoroughly an area was searched. The relationship between coverage and POD is usually plotted on a graph of POD vs. Coverage. Such a graph appears in Figure G-7.

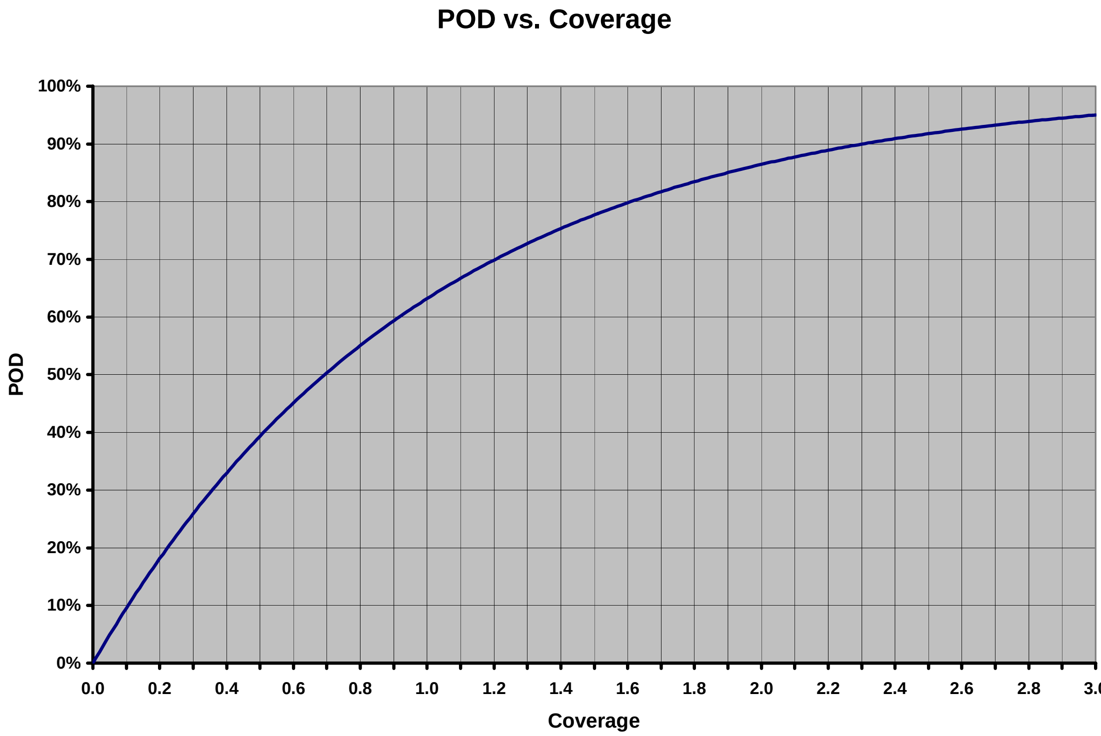
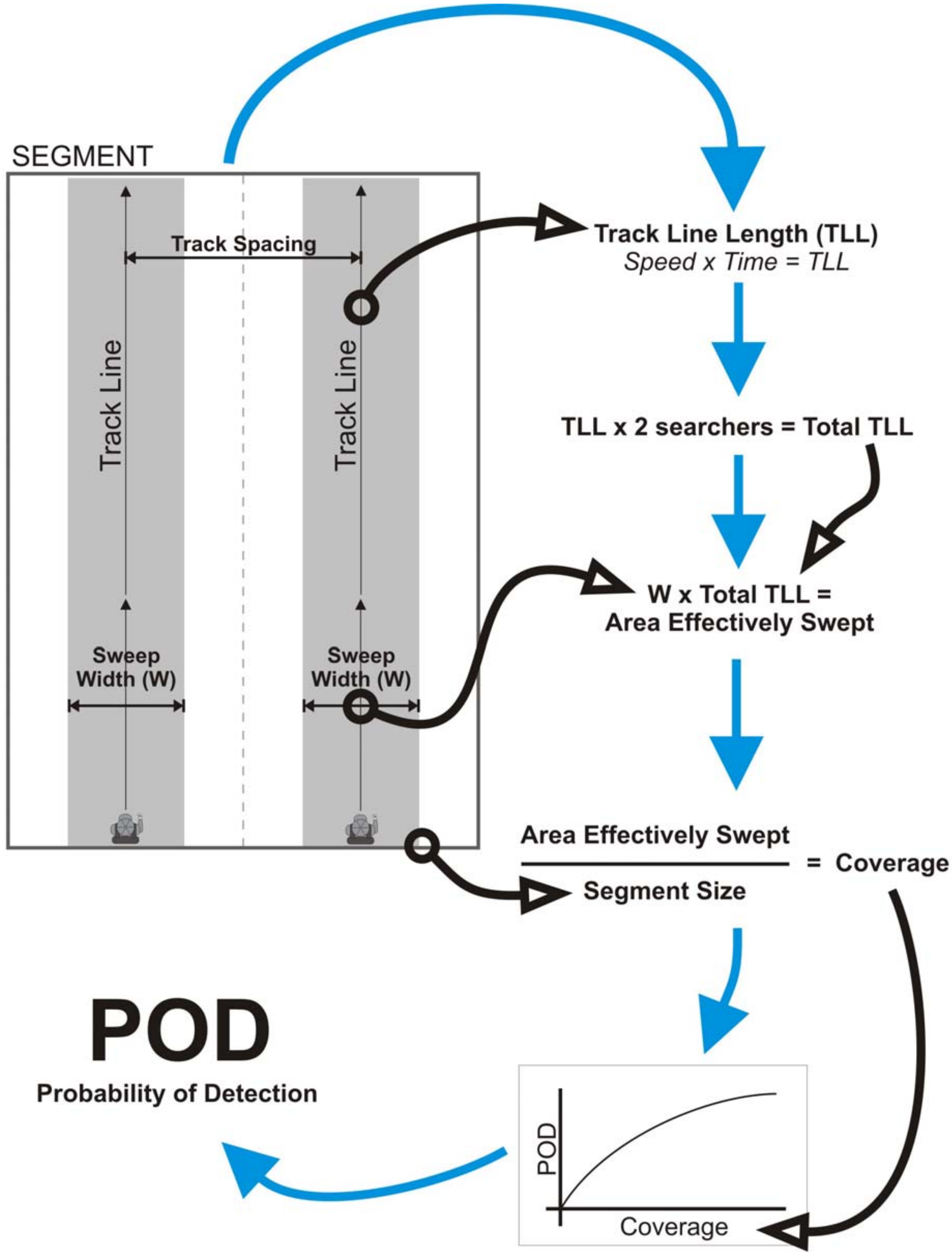


Figure G-7. POD vs. Coverage (Koopman, 1946)

POD in itself is not the goal of search planning as some of the land search literature has suggested. POD is merely one part of a larger system.

Appendix H. POD Illustration



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