**Selected Inland Search Definitions**
by Donald C. Cooper and John R. Frost

Introduction

In reviewing the inland search literature, it quickly becomes apparent that confusion is likely when a term is defined differently in various locations or when two terms are used to mean the same thing. It is recognized that many of these terms are not currently in general use in the ground search and rescue (SAR) literature. It is the intention of the authors here to offer factual, scientifically based definitions for terms that may be used in ground SAR operations and planning. In the interest of standardizing this terminology and reducing confusion, the authors also suggest that the following list of definitions and terminology be accepted and used by the inland search and rescue community.

The origins of many of the terms contained herein vary widely but includes operations research literature, international SAR literature (e.g., *The International Aeronautical and Maritime Search and Rescue* (IAMSAR) *Manual*) as well as conventional probability and statistics references.

The authors recognize that the definitions of these terms may be argued and improved over time as they are used and applied. In the interest of maximizing the usefulness of these terms, the authors would like to encourage interested parties to submit recommendations and suggestions for additions and/or modifications. The authors may be reached at the following E-mail address: cooper@raex.com. This list will be revised at regular intervals and made available for distribution.

Notation

A descriptive and complete notation is required to insure that terms are not confused. The notations illustrated in Sidebar 1 will be used to insure accuracy and consistency.

Selected Definitions

**Area Effectively Swept** (Z) **–** A measure of the area that can be (or was) effectively searched by searchers within the limits of search speed, endurance, and effective sweep width [IMO/ICAO, 1999b]. The *area effectively swept* (Z) equals the effective sweep width (W) times search speed (V) times hours spent in the search area (T) (Z = W x V x T) for one searcher or one resource (such as a boat or aircraft and its crew). Alternately, Z = W x D, where D is the lineal distance traveled. The unit of measurement for the *area effectively swept* is described in area (i.e., square miles, etc.). If multiple searchers simultaneously follow independent paths when searching and together achieve approximately uniform coverage of the segment, then the total *area effectively swept* is given by Z = n x W x V x T where n is the number of searchers. "*Area Effectively Swept*" is also referred to as "Search Effort" and the lineal distance traveled is also referred to as "Resource Effort" or just "Effort." Note: The amount of *area effectively swept* does **not** equal the amount of ground actually viewed by the searchers while searching. The amount of *area effectively swept* is the amount of area that would have been swept by a hypothetical sensor that was perfect (100% effective) over a swath as wide as the effective sweep width centered on each searcher's track and completely ineffective (i.e., made no detections) outside that swath. No such sensor exists, of course, but the concept of "*area* *effectively swept*" is nevertheless valid and useful for computing coverage, and using coverage to estimate probability of detection (POD).

**Estimated Position** (EP) – Last computed estimated position for a lost search object.

**Coverage** (C, also known as Coverage Factor, Effort Density) – The ratio of the area effectively swept (Z) to the area searched (A) or C = Z/A [IMO/ICAO, 1999b]. For parallel sweep searches where the searcher tracks are perfectly straight, parallel, and equally spaced, it may be computed as the ratio of effective sweep width (W) to track spacing (S) or C = W/S. "A" (area searched) and "Z" (area effectively swept) must be described in the same units of area. "W" (effective sweep width) and "S" (track spacing) must be expressed in the same units of length. *Coverage* may be thought of as a measure of "thoroughness." The POD of a search is determined by the coverage, as shown in Figure 1 [Koopman 1946]. Perfectly executed parallel sweep searches under ideal search conditions may achieve POD values somewhat higher than those shown in Figure 1.

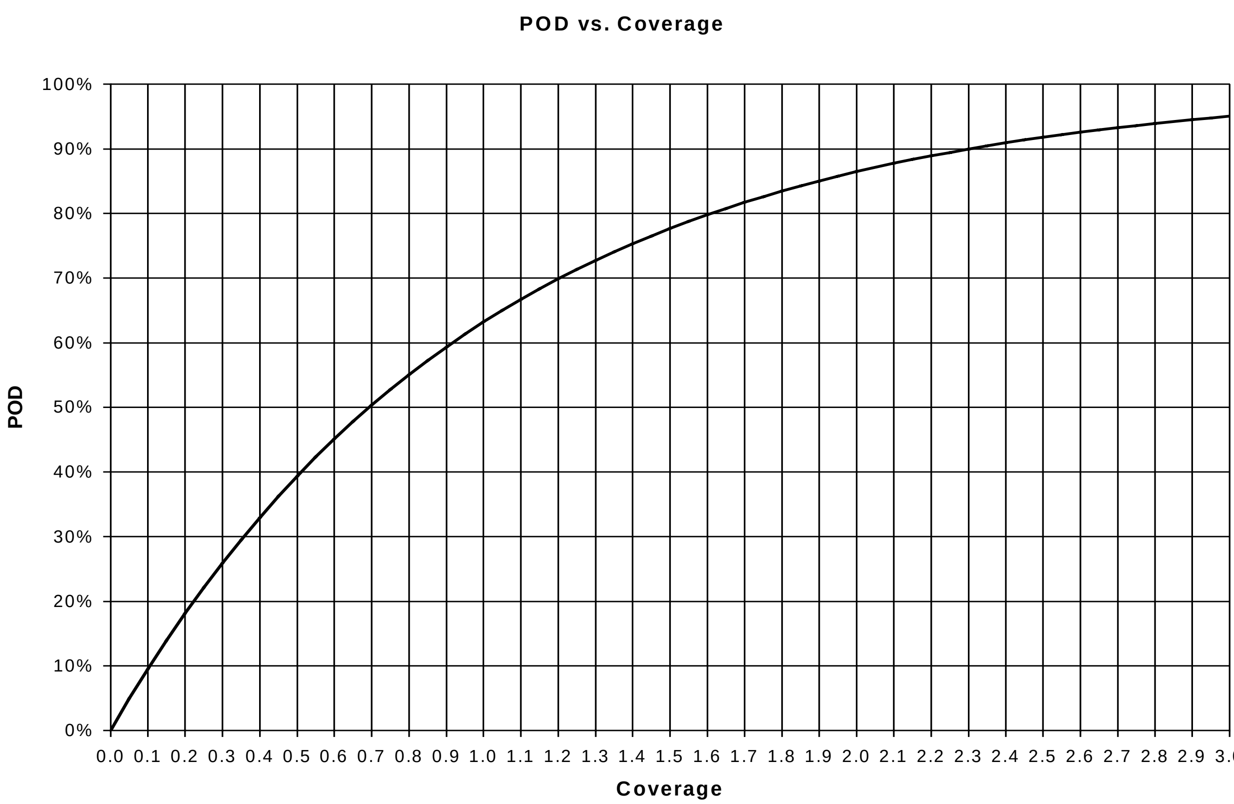


Figure 1 – POD vs. Coverage Curve [Koopman, 1946]

**Defective Distribution** (also known as Defective Probability Density Distribution) – A probability density distribution that contains less than 100% of the search object's possible locations under a given scenario or set of scenarios. [Stone, 1989].

**Effective Sweep Width** (W) **–** A measure of the effectiveness with which a particular sensor can detect a particular object under specific environmental conditions [IMO/ICAO, 1999b]. A measure of "detectability." *Effective sweep width* depends on the search object, the sensor and the environmental conditions prevailing at the time and place of the search. There is no truly simple or intuitive definition. Actual *effective sweep width* values for specific situations must be determined by rigorous scientific experiments. However, reasonably accurate estimates may be made from tables of *effective sweep widths* that have been determined by rigorous experiments for various typical search situations by applying appropriate "correction factors" to accommodate other search situations. A less accurate method of estimation for visual search is to assume the *effective sweep width* equals the "visual distance," or average maximum detection range (both of which are different ways of thinking of the same value). Since the relationship between *effective sweep width* and maximum detection range is not consistent across all search situations, this method may either over-estimate or under-estimate the correct value. Therefore, it should be used only until more accurate *effective sweep width* data is available (which will probably require a government sponsored and funded research effort).

The *effective sweep width* may be thought of as the width of a swath centered on the sensor's track such that the probability of failing to detect an object within that width equals the probability of detecting the same object if it lies outside that width, assuming the object is equally likely to be anywhere. Another equivalent definition is: If a searcher passes through a swarm of identical stationary objects uniformly distributed over a large area, then the *effective search (or sweep) width* (*W*) is defined by the equation,

$$W = \frac{\text{Number of Objects Detected Per Unit Time}}{(\text{Number of Objects Per Unit Area}) \times (\text{Searcher Speed})},$$

where all values are averages over a statistically significant sampling period [Koopman 1946]. Note that *effective sweep width* values are at least partially dependent on search speed. Generally speaking, a significant increase in search speed will decrease the *effective sweep width*. *Sweep width* (W) is needed to compute the area effectively swept (search effort or Z), and Z is needed to compute the coverage (C) based on the amount of search effort expended in the segment relative to the segment's physical area. The POD may then be derived from the POD vs. Coverage graph (Figure 1).

**Effort –** The linear distance traveled (V x T) by one searcher or one resource. The unit of measure for *Effort* is in linear distance. Used in the calculation of *Area Effectively Swept*.

**Last Known Position** (LKP) **–** Last witnessed or reported position of a lost search object [IMO/ICAO, 1999b].

**On Scene Endurance –** The amount of time a facility (resource) may spend at the scene engaged in search and rescue activities [IMO/ICAO, 1999b].

**Optimal Resource Allocation –** The process of determining where to assign the available search resources so that they produce the maximum possible probability of success (POS) in the minimum time.

**Optimal Search Plan –** A plan that maximizes the probability of finding the search object in the minimum amount of time by using the results of the optimal resource allocation process.

**Parallel Sweep Search –** A search tactic where one or more sensors, searchers, or resources (e.g., a helicopter) search an area by following a pattern of straight equally-spaced parallel tracks. Primarily used by vessels and aircraft, and for very thorough ground searches (e.g., evidence searches in conjunction with police investigations). Advantages include more uniform coverage of open areas and often a somewhat higher POD in such areas for a given level of effort than other techniques. While it is always a good idea to search any area in an organized fashion with a uniform coverage (until sufficient evidence is discovered to suggest another technique, such as tracking), in many ground search situations the terrain and ground cover make strict maintenance of straight tracks and equal spacing both impractical and counterproductive. However, an approximation to a *parallel sweep search* is often useful to help assure reasonably uniform coverage.

**Possibility Area –** (1) The smallest area containing all possible survivor or search object locations. (2) For a scenario, the *possibility area* is the smallest area containing all possible survivor or search object locations which are consistent with the facts and assumptions used to form the scenario [IMO/ICAO, 1999b].

**Probable Success Rate** (PSR) **–** The rate at which the probability of success (POS) is increased over time as the search progresses. An optimal search plan attains the maximum PSR possible from the available resources.

[1]

$$PSR = W \times V \times Pden$$

Where: $W$ is the effective sweep width.
$V$ is the search speed.
$Pden$ is the probability density.

**Probability Density** (Pden) **–** The ratio of a region's or a segment's probability of area (POA) to its physical area.

[2]

$$Pden = \frac{POA}{Area}$$

**Probability Map –** An illustration of the distribution of search object location probability over the possibility area where each cell or region is labeled with the probability of the search object being in that cell or region [IMO/ICAO, 1999b]. Initially, *probability maps* are formed from a largely subjective analysis of the available information (LKP, terrain, evidence, clues, historical trends, lost person behavior profiles, etc.). This information is evaluated to determine regions (see "Region") where the subject might be at the time of the search based on one or more scenarios (see "Scenario"). It quantifies the probability of the subject being in each region, as shown in Figure 2. (See "Initial POA" under "Probability of Area.")

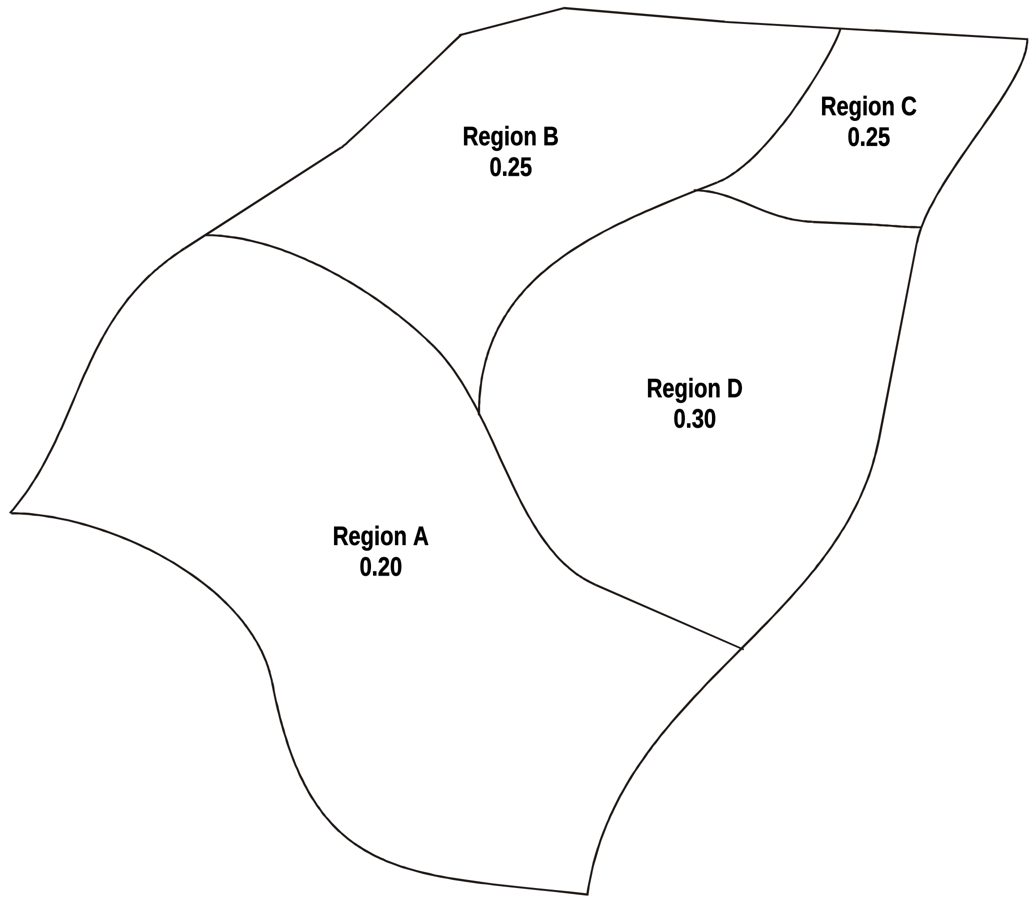


Figure 2 – A search area with four regions and their POA values after a consensus.

If the regions are subdivided into searchable segments, segment POA values are determined from the regional POA in proportion to the segment areas. It is assumed that the probability density is constant throughout any one region. That is, the ratio of segment POA to region POA is the same as the ratio of segment area to region area, as shown in Figure 3. If the Pden is not constant throughout any one region, the number of regions and choice of regional boundaries should be refined until it is no longer possible to distinguish parts of regions on the basis of Pden.

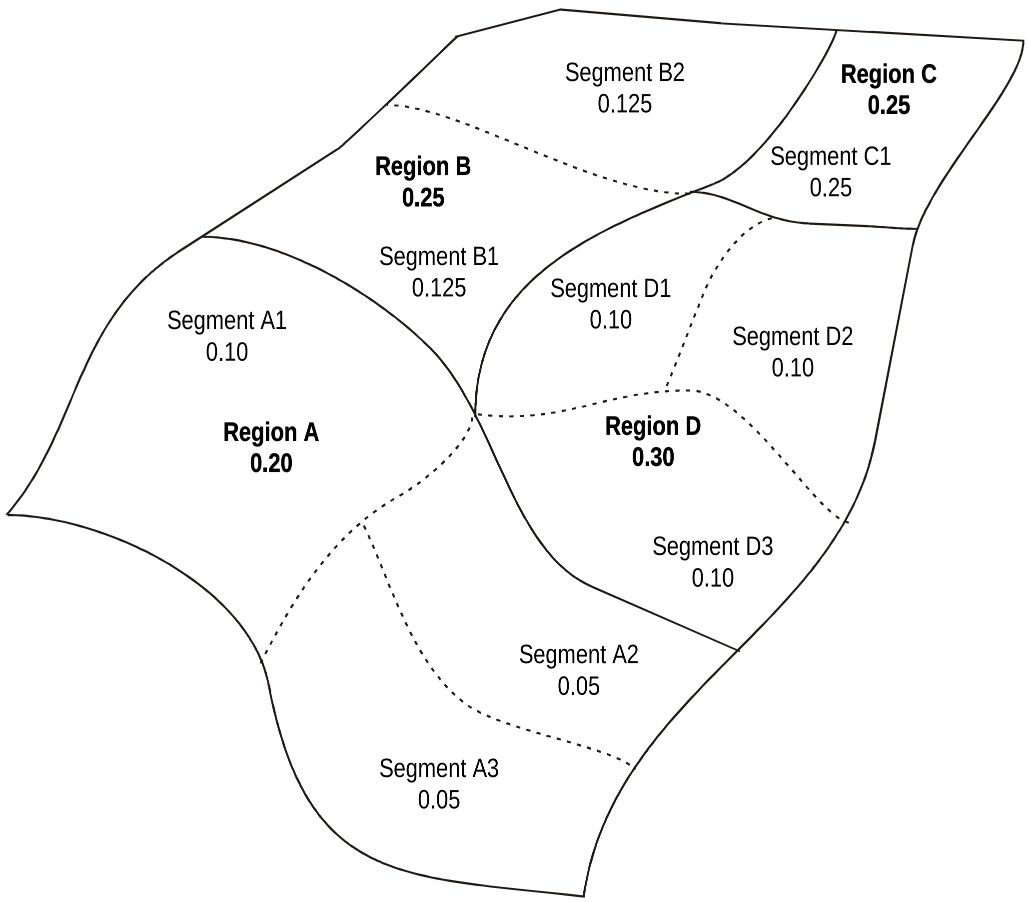


Figure 3 – Segments within regions and their associated POA values.

In its purest mathematical form, a *probability map* consists of a regular grid of cells all of equal area as shown in Figure 4. Cellular probabilities are determined in the same way as segment probabilities. That is, each cell is assigned a fraction of the region's POA value in proportion to the fraction of the region's area contained in each cell. For cells that span regional boundaries, POA values are computed as the sum of the contributions from each region, pro-rated by the fractions of the regional areas contained in the cell. Although most useful in an open "unbounded" uniform environment (e.g., the ocean), this type of display may also be useful in mixed environments and has at least one advantage. When all the cells all have the same area, the POA values are proportional to the probability density (Pden) values so it is easy to tell at a glance where both POA and Pden values are high and where they are low. Note that by examining those cells that are completely contained within a region, it is clear that Region C has the highest density. It is also possible to tell that the Pden in Region C is nearly three times that of Region D. With segments or regions having unequal areas, it is possible to have a high POA and a low Pden and vice versa. Note that the POA of Region C is less than that of Region D. In general, Pden is more important to optimal resource allocation than POA.

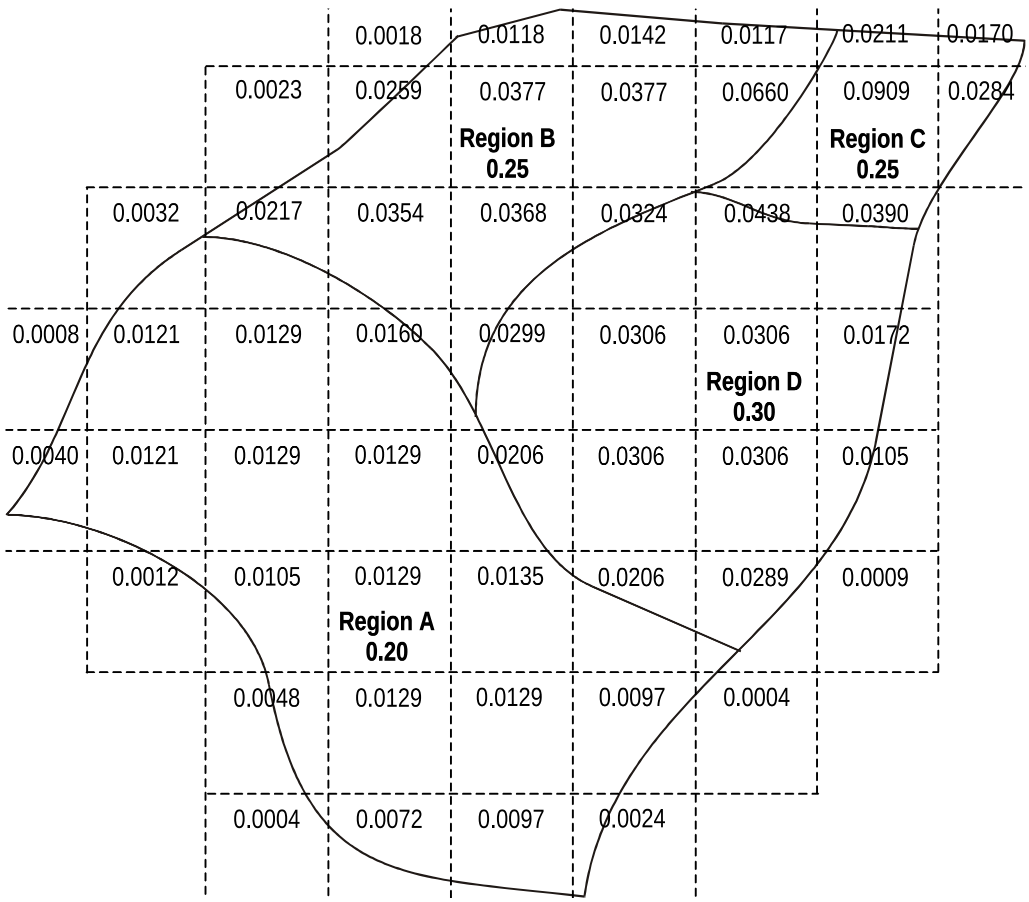


Figure 4 – A search area showing regions and a grid overlay.

A *probability map* may be made more readable by multiplying all the probabilities by some convenient constant. For example, if the cellular probabilities were all multiplied by 100, then 0.0129 would become 1.29%. Another technique (used in the original version of the U. S. Coast Guard's Computer Assisted Search Planning (CASP) system) is to multiply all the cellular probabilities by 10,000 and record the results as whole numbers. In this case, 0.0129 would become 129.

**Probability of Area** (POA, also known as Probability of Containment or POC) – The probability that the search object is contained within the boundaries of a region, segment, or other geographic area. Regional *POA* values are generally determined by consensus and scenario analysis. Segment *POA* values may be computed from regional probability densities and segment areas.

*Adjusted, Shifted or Updated POA* ($POA_{s,n}$) – The modified POA of a segment after an unsuccessful search in that segment. Used to measure the decrease in the probability that the search object is in the segment after the segment has been searched. The following equations represent various methods of obtaining $POA_{s,n}$.

[3] $$POA_{s,n} = POA_{s,n-1} \times (1 - POD_{s,n})$$

[4] $$POA_{s,n} = POA_{s,n-1} - (POD_{s,n} \times POA_{s,n-1})$$

[5] $$POA_{s,n} = POA_{s,n-1} - POS_{s,n}$$

[6] $$POA_{s,n} = POA_{s,0} \times (1 - PODcum_{s})$$

[7] $$POA_{s,n} = POA_{s,0} - (PODcum_{s} \times POA_{s,0})$$

[8] $$POA_{s,n} = POA_{s,0} - POScum_{s}$$

Note: The *adjusted POA* values computed by the above formulas are not normalized. That is, the sum of the *adjusted POA* values will not equal the sum of the initial POA values. The omission of normalization is deliberate and necessary to the correctness of the formulas and definitions presented herein. Removal of the normalization computations does not violate the laws of probability and statistics in this context. Removal of normalization also substantially reduces the computational burden of maintaining *adjusted POA* values and preserves enough information about the search to make all other probability values of interest easily computable.

*Initial POA* (POAinitial) or *Consensus POA* ($POA_{s,0,c}$) – The initial POA assigned prior to any searching. *Initial POA* values must be based on a careful and thorough evaluation of all the available evidence, data, clues, etc., pertinent to the incident. *Initial POA* values, or the relative values used to compute them, must be in the correct proportions to one another. A region with an assessed value of “8” on a scale of 0 to 10 must be twice as likely, in the view of the evaluator making the assessment, to contain the search object as a region that is assigned a “4.” Similarly, a region with a POA of 20% must actually be viewed as twice as likely to contain the object as one with a POA of 10%. If, upon review before the evaluator submits his/her values the proportional relationships among the regional assessment values do not pass this test, then they should be revised until the evaluator feels they do correctly reflect his/her views in this regard. If the relative assessment values used are in the correct proportions, the POA percentages computed from them will also be in the correct proportions. The consensus POA values computed from the individual assessments should then be an accurate reflection of the collective views of the evaluators.

Ideally, the search area will be divided into some number of regions based on the available evidence, data, clues, etc., which bear on where the subject is more likely and less likely to be at the time of the first search. POA values would then be assigned to these regions. If necessary, these regions may be sub-divided into searchable segments. Segment POA values would be computed by prorating the region's POA among the region's segments by segment area. That is, a segment one-third as large as the region would get one-third of the region's initial POA as its initial POA value. Stated as a formula:

$$POA_{s,0,c} = POA_{R,0,c} \times \frac{A_{s,c}}{A_{R,c}} \quad [9]$$

Where: $POA_{s,0,c}$ is the initial POA value for segment s in region R based on consensus c. Hereafter, it will be assumed that all values are based on the same consensus c if this subscript is omitted.

$POA_{R,0,c}$ is the initial POA value for region R based on consensus c.

$A_{R,c}$ represents the area of region R from consensus c.

$A_{s,c}$ represents the area of segment s in region R.

If a new consensus is necessary and new initial regional and segment POA values are established there is no need to discard all information about previous searching (i.e., segment POD values). Assuming that segment boundaries do not change, new adjusted segment POA values may be computed using the following procedure (the formulas show how to get from the adjusted POA values of the first consensus to those of the second consensus):

- Compute new initial segment POA values based on the new regional POA values from the new consensus using equation [9] above. (Note that $A_{s,2} = A_{s,1}$.)

$$POA_{s,0,2} = POA_{R,0,2} \times \frac{A_{s,2}}{A_{R,2}}$$

- Compute the cumulative POD for each segment (see *Cumulative Segment POD* ($PODcum_s$) under Probability of Detection below) using equation [10] (preferred) or [11] or [12] below.

$$PODcum_s = 1 - \left( \frac{POA_{s,n,1}}{POA_{s,0,1}} \right)$$

- Multiply the new initial segment POA by one minus the cumulative segment POD to get the new adjusted POA by using equation [6] above.

$$POA_{s,n,2} = POA_{s,0,2} \times (1 - PODcum_s)$$

**Probability of Detection** (POD, $POD_{s,n}$) – The probability of the search object being detected, assuming it was in the segment searched. $POD_{s,n}$ measures sensor effectiveness, thoroughness, and quality for search n of segment s. $POD_{s,n}$ is a function of the coverage (C) achieved in segment s by search n, as shown in Figure 1.

*Cumulative Segment POD* ($PODcum_s$) - After the same segment is searched multiple times, the chances of having detected the search object, if it was present in the segment the whole time, are increased as compared to having searched the segment only once. This increasing probability of detecting a search object after multiple searches in the same segment is called *cumulative segment POD.*

[10] $$PODcum_s = 1 - \left(\frac{POA_{s,n,1}}{POA_{s,0,1}}\right)$$

[11] $$PODcum_s = \frac{POScum_s}{POA_{s,0}}$$

[12] $$PODcum_s = 1 - ((1 - POD_{s,1,c}) \times (1 - POD_{s,2,c}) \times \ldots \times (1 - POD_{s,n,c}))$$

*Predictive POD* – estimated POD computed by search planners prior to the search of a segment based on predicted values for effective sweep width (W), area that will be effectively swept (Z), and coverage (C).

*Retrospective POD* – POD computed by using information obtained from debriefing the searchers to estimate the effective sweep width (W), area effectively swept (Z) and coverage (C) after the search of a segment.

**Probability of Success** (POS) - The probability of finding the search object with a particular search. POS measures search effectiveness.

*Cumulative Probability of Success* (POScum) - The accumulated probability of finding the search object with all the search effort expended over all searches to date [IMO/ICAO, 1999b]. POScum may be computed for a segment, in which case it can never exceed the initial segment POA, or it may be computed for all searching in all segments to date (overall POScum or OPOScum [see below]), in which case it can never exceed the total of all initial POA values (usually 1.0 or 100%).

*Segment POS* ($POS_{s,n}$) – The probability of finding the search object in the segment on a particular search (i.e., during a particular operational period).

[13] $$POS_{s,n} = POA_{s,n-1} - POA_{s,n}$$

*Segment POScum* ($POScum_s$) – The sum of the POS values for each search in a particular segment.Used to measure the increasing possibility that the search object is outside of the segment described. This value can never exceed the initial POA value assigned to the segment. $POScum_s$ is a measure of search effectiveness to date in this segment.

[14] $$POScum_s = POS_{s,1} + POS_{s,2} + \ldots + POS_{s,n}$$

[15] $$POScum_s = POA_{s,0} - POA_{s,n}$$

[16] $$POScum_s = POA_{s,0} \times PODcum_s$$

*Overall POScum* (OPOScum) - The sum of all individual segment POScum values. Used to measure the increasing possibility that the search object is outside of the search area and the decreasing probability (1- OPOScum) that further searching based on the present scenario(s) will be successful. OPOScum is a measure of overall search effectiveness.

[17] $$OPOScum = \Sigma POA_{s,0} - \Sigma POA_{s,n}$$

[18] $$OPOScum = \sum_{s=1}^{m} POScum_s$$

**Resource Effort** – See "Effort."

**Region** (R) – A subset of the search area based only on factors that affect POA (*regions* may require segmentation prior to searching). *Regions* are based on probability of the search object's location, not on suitability for assigning search resources. A *region* may contain searchable segments, or a *region*, itself, may be a searchable segment. A searchable segment may also contain one or more *regions* (based on probability) but rarely is the available data good enough to distinguish such small r*egions* in ground search situations.

**Scenario** – A consistent set of known facts and assumptions describing what may have happened to the survivors [IMO/ICAO, 1999b]. A description of what the subject(s) may have done and what the subject(s) may have experienced since last seen or known to be safe. A *scenario* should be consistent with a significant part of the available evidence and data. Normally, multiple *scenarios* should be considered especially when not all the available pieces of evidence and data are consistent with all other pieces.

**Search** – An operation, normally coordinated, that uses available resources, personnel and facilities to find persons in distress or objects whose exact location is unknown. From the incident coordinator's perspective, incidents where the subject's location is initially not known are largely investigative in nature. *Searching* is but one of the tools available for resolving the incident, albeit the one that is the most expensive, labor-intensive, risky, and difficult to use – making it the tool of last resort [IMO/ICAO, 1999b].

**Search Area** – The area, determined by the search planner, that is to be searched. The *search area* may be divided into regions based on the probable scenarios and into segments for the purpose of assigning specific responsibilities to the available search resources [IMO/ICAO, 1999b].

**Search and Rescue Facility** – Any mobile resource, including designated search and rescue units, used to conduct search and rescue operations [IMO/ICAO, 1999b].

**Search and Rescue Unit** (SRU) – A unit comprised of trained personnel and provided with equipment suitable for the expeditious conduct of search and rescue operations [IMO/ICAO, 1999b].

**Search Effort –** See "Area Effectively Swept."

**Search Endurance –** The amount of "productive" search time available at the scene. [IMO/ICAO, 1999b].

**Search Object –** A ship, aircraft or other craft missing or in distress or survivors or related search objects or evidence for which a search is being conducted [IMO/ICAO, 1999b]. A generic term used to indicate evidence (clue) related to a lost subject or the lost subject. In the same segment, different search objects generally have different effective sweep widths (or "detectabilities"). This means that for any given search of a segment, different coverages, and hence different POD values, will be achieved for different *search objects*.

**Search Speed** (V) **–** The average rate of travel (speed over the ground) of searchers while engaged in search operations within a segment [IMO/ICAO, 1999b].

**Segment** (s) **–** A designated sub-area (subset of the search area) to be searched by one or more specifically assigned search resources. The search planner determines the size of a *segment*. The boundaries of a *segment* are identifiable both in the field and on a map and are based on searchability, not probability.

**Sensor –** Human senses (sight, hearing, touch, etc.), those of specially trained animals (such as dogs), or electronic device used to detect the object of a search [IMO/ICAO, 1999b]. A human, multi-sensor platform is often referred to as a "searcher."

**Sensor Track –** The actual path followed by a sensor while engaged in searching. For example, the actual path followed by a searcher carrying a GPS tracking device can be displayed on several computer-based mapping systems.

**Sortie –** The individual movement of a resource in conducting a search or rendering assistance [IMO/ICAO, 1999b].

**Sweep Width –** See "Effective Sweep Width."

**Track Spacing –** The distance measured between adjacent tracks of a parallel sweep search pattern.

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## Sidebar 1 - Notation Used Herein

The first subscript (s) designates the segment or region, i.e., segment s, in this example.

The second subscript (n) designates the search number, i.e., search number n, in this example.

This is the adjusted POA value of segment s after search n, and is based on consensus c.

This is the adjusted POA value of segment s prior to search k, and is based on consensus c.

"k-1" designates the search just prior to search k.

$$POA_{s,n,c} = POA_{s,k-1,c} \times (1 - PODcum_{s,(k,\ldots n)})$$

The third subscript (c) designates the consensus number; that is, consensus 1, consensus 2, etc. This subscript will usually be omitted and presumed to be 1 (the first consensus) unless otherwise specified.

This is the cumulative POD for segment s where (k,…n) is optional and denotes the searches (k through n) included in the computation. For example, $PODcum_{s,(3,4,5)}$ denotes the cumulative POD for searches 3, 4, and 5 only in segment s.

If the (k,…n) subscript is not shown with $PODcum_{s}$, the inclusion of all searches (i.e., 1, … n) in segment s is implied, making k = 1 everywhere in this equation.

## Sidebar 2 – Standard Symbols for Terms Defined Herein

| | |
|---|---|
| A | Area |
| C | Coverage |
| c | Consensus (usually denotes the consensus number, e.g., first consensus, second consensus, etc.) |
| CASP | Computer Assisted Search Planning (US Coast Guard software) |
| cum | (as subscript) denotes cumulative value of associated term (e.g., $POD_{cum}$ is cumulative POD) |
| EP | Estimated Position (usually computed) |
| LKP | Last Known Position |
| n | Search number |
| Pden | Probability Density |
| POA | Probability of Area |
| POC | Probability of Containment (identical to POA) |
| POD | Probability of Detection |
| POS | Probability of Success |
| PSR | Probable Success Rate |
| R | Region |
| S | (upper case) Track Spacing |
| s | (lower case) Segment |
| SRU | Search and Rescue Unit |
| T | Time |
| V | Velocity or Speed |
| W | Effective Sweep Width |
| Z | Area Effectively Swept (also known as Search Effort) |