A Pragmatic Approach to Applied Search Theory

Guy Mansfield PhD, **Joe Carlson** BA, **Danny Merrifield** MS,
Eric Rosenberg BA, **Erik Swanson** BA, **Peter Templin** BS
Washington State SAR Planning Unit
USA
Email: jgmansfield@msn.com

Abstract

The Washington State SAR Planning Unit (SSPU) was activated in 2018 to provide advanced search planning resources to regional incident commands during extended or complex search missions. The SSPU operates under the auspices of the Washington State Emergency Management Division, and comprises experienced SAR volunteers with specialized training in search management and planning. In addition to providing search planning strategies and technical mapping, one of the primary objectives of the SSPU is to apply modern search theory to challenging search incidents.

Our application of search theory can be parsed into three related planning tasks: (1) Characterizing initial search regions and segments; (2) Assessing search effectiveness; and (3) Prioritizing search assignments for subsequent operational periods. A major challenge faced in achieving these objectives is that the SSPU can be requested by any of the 39 counties in Washington State, all with different search planning approaches, different search data collection practices, and different experience with the principles of modern search theory. For this reason, the SSPU has developed a pragmatic approach to applied search theory that can be characterized in one phrase: "When objective data are available, use it according to search theory best practices; when only subjective input is available, at least be systematic".

KEY WORDS: *Search theory, search planning.*

Introduction

The Washington State SAR Planning Unit (SSPU) was envisioned in 2015 by Chris Long (Washington State SAR Coordinator) and Jon Wartes (King County Search and Rescue) as a team of specially-trained volunteer technicians who would be able to assist Washington State counties with search planning for complex or extended search incidents. They recognized that search theory as applied to land searches, had progressed to the point where it was applicable to real search missions. This new circumstance called for "planning technicians" who were trained in underlying search theory concepts, were familiar with the tactical implications of applying search theory, and who had the ability to use modern software tools to support planning activities. Under the leadership of Long and Wartes, a group of experienced SAR volunteers were selected and trained during 2016-2017, and the SSPU was formally activated in early 2018.

Planning services provided by the SSPU can come in two forms:

1. We can develop and deliver a Remote Search Plan. Remote Search Plans are based on the concept of a Virtual Search Plan, developed by Paul Burke of the Nevada State Sheriff's Department (Burke, 2017). Remote Search Plans comprise an incident overview, detailed subject research, search scenarios, terrain analysis, recommended search objectives, and detailed search maps – all based on search planning best practices where possible. Remote Search Plans are produced via online collaboration of SSPU team members and are delivered electronically to on-site Incident Command.

2. We can provide on-scene planning resources. If requested, SSPU team members will travel to the search incident and provide on-site services that can include: Search theory-based planning, technical mapping, recommended search assignments and priorities, as well as a Planning Section Chief or Situation Unit Leader. Typically, on-scene SSPU staff will integrate and work closely with the command staff of the host county in a unified effort.

Search jurisdictions in Washington State (39 counties and 3 national parks) are diverse in their environments, their search planning experience, and their exposure to modern land search theory. For that reason, when the SSPU is activated, we must adapt our planning methods to make optimal use of local conditions, local data availability, and local expectations. Our approach to this challenge has been to develop a framework that guides decisions about what components of search theory can be applied under what circumstances. Within this framework, we have attempted to create standardized processes, checklists, and tools to facilitate the use of search theory-based best practices.

In this paper, we describe our initial attempt at this framework, divided into three components: (I) Characterizing Search Regions and Segments; (II) Assessing Search Effectiveness; and (III) Prioritizing Search Assignments.

I. Characterizing Search Regions and Segments

A. Defining the Search Area Boundary

As a prelude to defining the Search Area and Search Regions, we generate and formally evaluate Search Scenarios. We use a Proportional Consensus process (supported by a simple spreadsheet tool) to assign relative priorities to Search Scenarios. These prioritized Search Scenarios then drive formation of search objectives, and guide decisions about which objectives to address first. We will sometimes include as a scenario that the subject has traveled outside of the active search area. This scenario (sometimes formalized as "Rest of the World" or ROW), serves to remind search managers of this possibility, but is not defined formally as a Search Region and is not used in quantitative search theory calculations (Cooper et al, 2003).

Our process for defining search regions and segments begins with current best practices for outlining a Search Area Boundary, using (1) theoretical travel distances; (2) historical travel distances based on Lost Person Behavior (LPB) data (Koester, 2008); (3) analysis of terrain features; and (4) subjective inferences (Stoeffel, 2006). In our consideration of the influence of terrain features on subject travel, we have become particularly sensitive to two factors: The value of local knowledge, and the influence of linear features as travel aids. Both of these factors are illustrated by the incident depicted in Figure 1, which shows the travel path of a lost subject in Mount Rainier National Park.

While not a new observation, time and again, the value of obtaining local knowledge of terrain features, old trails or tracks, and past subject behavior in the search area has been demonstrated to us. This was well-illustrated by a 2018 search for a lost backpacker in the Spray Park area of Mount Rainier National Park. Rangers on the planning team were able to recall previous episodes when lost persons in that area worked their way down a narrow creek drainage and ended up wandering to the west down the Mowich River Basin. This detailed local knowledge turned out to be a key in locating the subject.

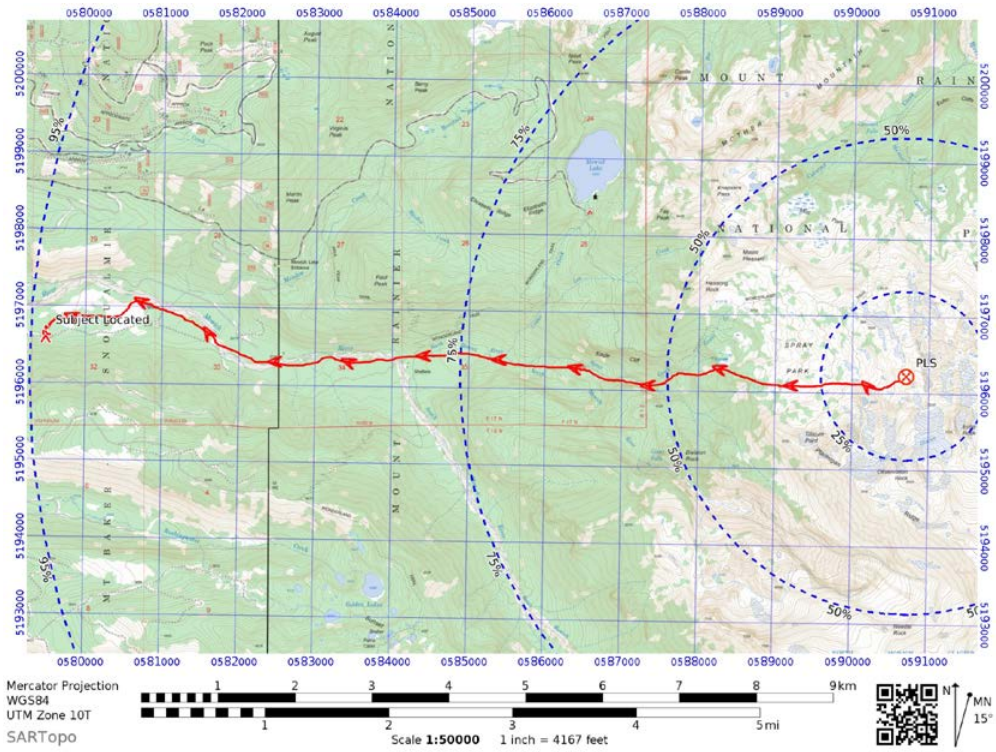

Figure 1: *A Subject's "Linear Escape" of Over 18 km*

As depicted by the red line in Figure 1, once into the river basin, the subject kept moving down this travel aid, performing what we now think of as a "linear escape". After three days of searching, the subject was located in the river basin over 19 km from the Point Last Seen (PLS) -- just at the 95% distance for the Hiker Lost Person Behavior subject category. Search planners (principal author included) had recognized this possibility and had directed a helicopter to search the river basin. What search planners did not do, was to provide specific guidance for how far down the basin to fly (*to the 95% distance would have been a good idea!*), and as a result, the helicopter crew did not fly far enough west. The subject was located (in good condition) by a ranger who had been directed to patrol forest roads in the far western area of the river basin.

While anecdotal, another example of a "linear escape" is the search for a hiker who went missing in 2017 in Olympic National Park. Extensive searching of ground and river terrain near his last known point (LKP) was conducted for months by both official and family resources. In 2018 the hiker's remains were found by park rangers just outside the 95% "lost hiker" radius – 19 linear km from the LKP and 24 km by trail. With these incidents in mind, we extend search area boundaries when appropriate by adding buffer search areas along linear features that might aid subject travel.

Sensitivity to the influence of linear features is also supported by a recent geospatial analysis of find locations with respect to terrain features (Jacobs, 2016). Based on an analysis of 622 ISRID incidents (for Hiker, Hunter, and Gatherer subject categories), Jacobs reported that the probability of find location increased near linear features, such as roads, trails, streams, and drainages. He suggested that terrain-based probability considerations could be applied in some incidents (particularly where terrain is not uniform) to focus search priorities on "*dense searching at the core [near the IPP] surrounded by a web of linear features, with several long-ranging stringers at the periphery*."

B. Characterizing Search Regions

Search Regions are defined and mapped as geographical areas inside which the Probability of Area (POA) is assumed to be uniform. That is, the likelihood of a subject being at any location in the region is the same for all locations within the region. Drawing and characterizing Search Regions yields a "probability map" which illustrates and quantifies the distribution of POA within the Search Area Boundary (IMO/ICAO, 1999b; Cooper and Frost, 2017). The POA of each Search Region is the starting point for applying search theory to evaluate its relative priority in search planning.

Our approach to defining Search Regions depends upon (a) the nature of planning done by the local jurisdiction prior to SSPU involvement, and (b) availability of objective statistical data (e.g., Lost Person Behavior). If the SSPU is activated prior to or during the first operational period, we typically will define search regions using the approaches described below. On the other hand, if SSPU is activated after initial operational periods, we may adopt previously defined search regions if they seem adequate.

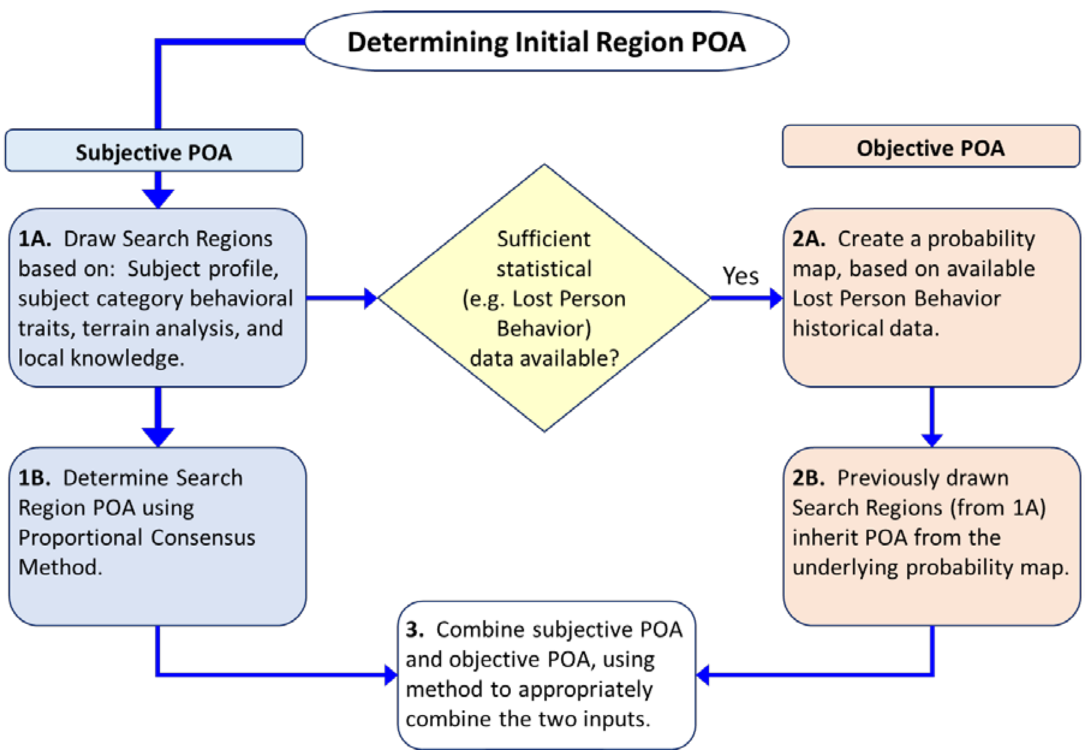

Figure 2: *Decision Guide for Characterizing Search Regions*

As diagrammed in Figure 2 [Step 1A], we begin with a "subjective" approach to defining and mapping Search Regions. Regions are defined using search scenarios, lost person behavior category, the effect of terrain on subject travel, attractions, deterrents, and time elapsed. Physical boundaries, such as terrain or man-made barriers, are also used in defining Search Regions. Once mapped, we use a proportional consensus method [Step 1B] to assign a Subjective POA to each Search Region.

Figure 3 below shows subjectively defined Search Regions (blue-shaded areas) for a missing snowshoer last seen at 8500 feet on the Muir Snowfield in Mount Rainier National Park. For this mission, during planning for Operational Period 2, SSPU members defined Search Regions based on: (a) the likelihood of travel in a given direction; (b) terrain guides (snowfield edges); (c) terrain barriers; and (d) distance from the PLS.

For example, Regions A and C were both within a relatively close distance from the PLS, and both on the Muir Snowfield proper. Region A was judged to have higher relative POA because it was consistent with the subject's presumed direction of travel (downhill to the trailhead). One can also see that the southern boundaries of Regions A, D, I, and F roughly correspond to 25% and 50% Distance from IPP radii (yellow dotted lines).

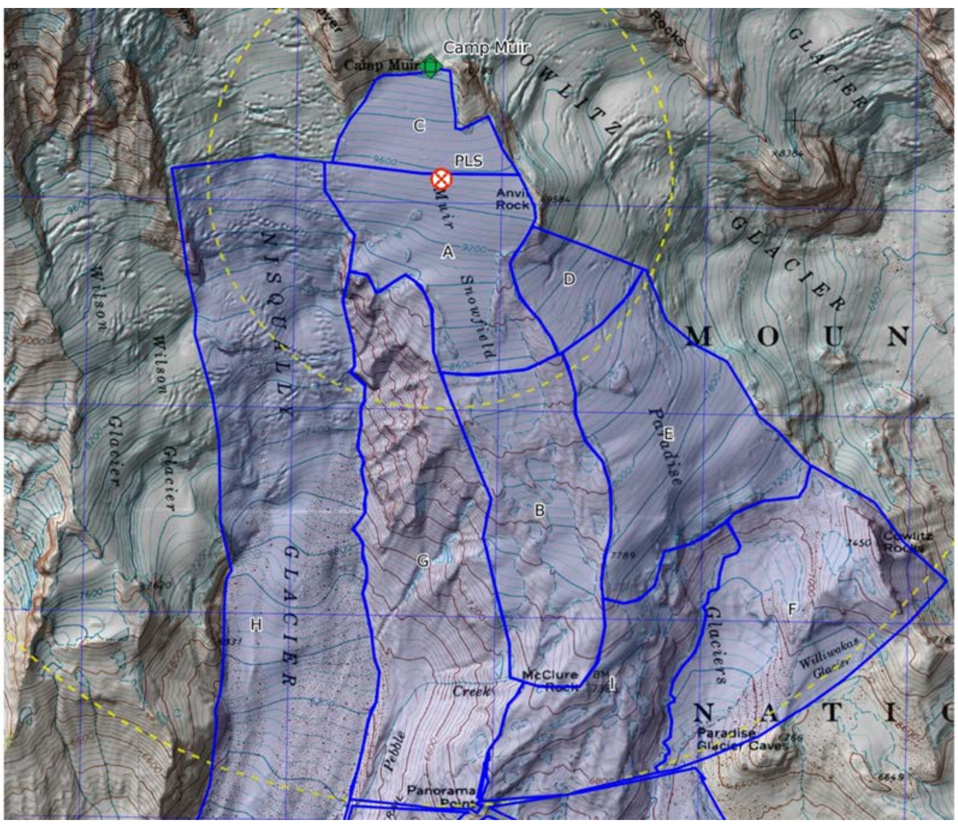

Figure 3: *Subjectively Defined Search Regions for Missing Snowshoer on Mount Rainier*

When multiple LPB factors are available, we attempt to objectively quantify Search Region POA via the approach described by Koester (Koester, 2018). This data-based POA quantification [Step 2A in Figure 2] involves the following general steps:

1. Obtain LPB historical data for at least two (preferably three or more) factors, such as: (1) Distance from IPP, (2) Dispersion Angle, (3) Track Offset, and (4) Elevation Change.

2. The historical percent of finds, as shown for two LPB factors in Table 1 below, form the basis for a probability map used to quantify Objective POA (Koester, 2008).

Lost Person Behavior Factor	**25%**	**50%**	**75%**	**95%**
Distance from IPP	1.1 km	3.1 km	5.8 km	11.3 km
Contribution to Objective POA	25	25	25	20

Lost Person Behavior Factor	**25%**	**50%**	**75%**	**95%**
Dispersion Angle	2^{o}	23^{o}	64^{o}	132^{o}
Contribution to Objective POA	25	25	25	20

Table 1: *Historical Lost Person Behavior Data for Hiker Category (Mountain, Temperate)*

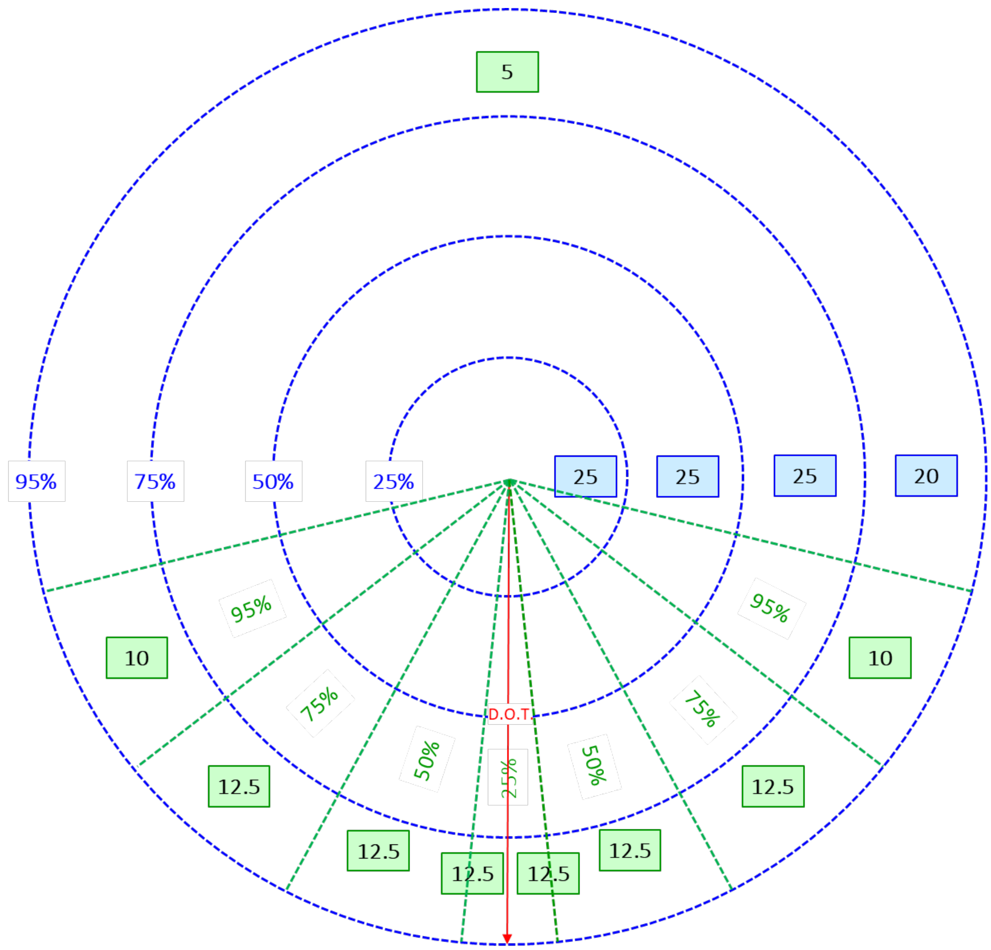

Figure 4: *Underlying LPB Values for Objective POA.*

Dotted blue lines represent Distance from IPP. Dotted green lines represent Dispersion Angle.

In this diagram, dispersion angles and distance radii have been reduced to simplify the exposition.

Figure 4 above, shows how two LPB factors (Distance from IPP and Dispersion Angle) would be combined to create a map of underlying POA values. The Objective POA value for each Distance from IPP ring or annulus comes directly from the historical "percent of finds" data in Table 1 above. Similarly, the Objective POA value for each Dispersion Angle sector derives directly from the LPB data for that factor. (Note that the POA values for each Dispersion Angle sector are halved on each side of the direction of travel, indicated by the red "D.O.T." line).

3. The LPB historical values illustrated in Figure 4 become the basis for a Probability Map in which the historical values are proportionally distributed to each unique intersect of a Distance from IPP ring/annulus with a Dispersion Angle sector. The principal for this is illustrated in Figure 5, where the purple area of the probability map represents the unique intersect of the 95% Distance from IPP annulus and the 95% Dispersion Angle sector. The POA for this area is calculated as follows: 7% of the area of the 95% distance from IPP annulus (20 * .07 = 1.3) plus 44% of the area of the 95% dispersion angle sector (10 * .44 = 4.4), yielding a POA of purple area = (1.3 + 4.4) = 5.7.

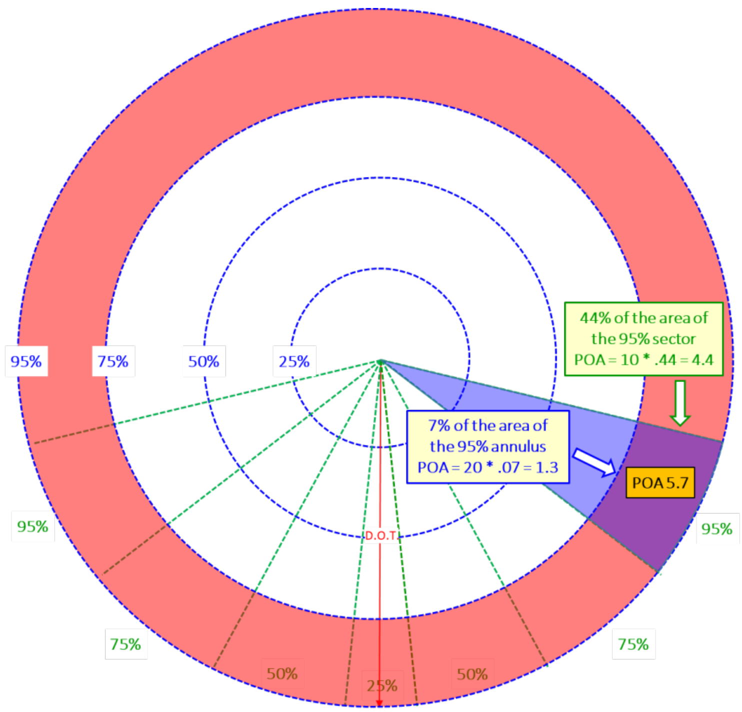

Figure 5: *Probability Map for One Unique Intersect.*

The fully quantified probability map for this two-factor example is shown in Figure 6 below.

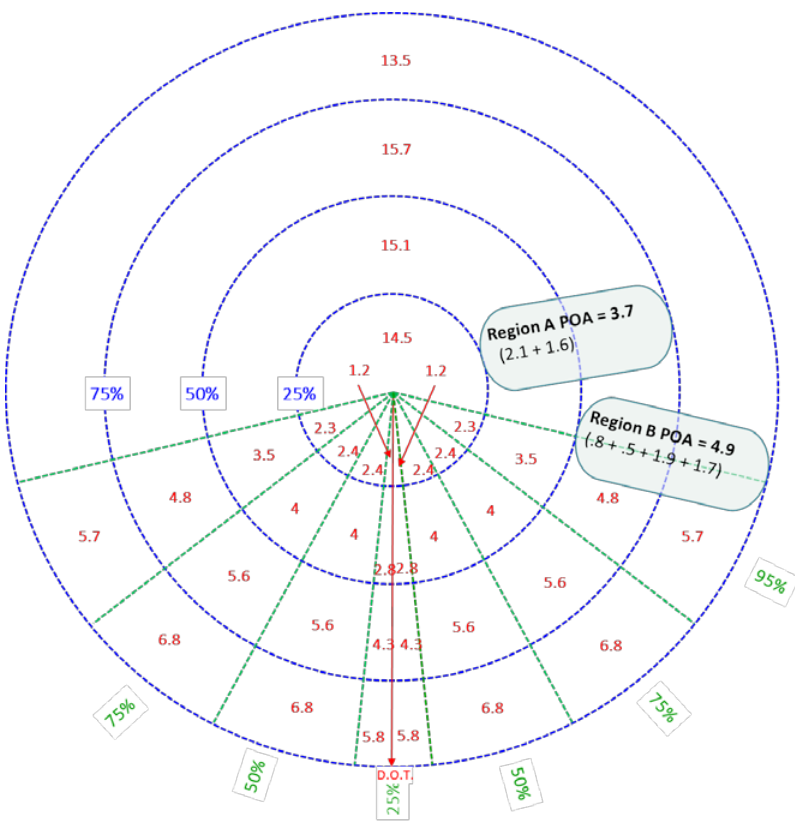

Figure 6: *How Search Regions Inherit Objective POA from an Underlying Probability Map*

4. After a probability map has been created based on historical Lost Person Behavior statistics, previously drawn Search Regions are overlaid on the probability map and "inherit" their Objective POA based the areas of probability covered by each region. Two examples of this are shown in Figure 6 above.

Region A contains two unique intersects, combining to yield a POA of 3.7.

- Region A covers 14% of the portion of the 50% annulus that is not covered by a Dispersion Angle sector. The POA for that intersect is calculated as (15.1 * .14) = 2.1
- Region A also covers 10% the portion of the 75% annulus that is not covered by a Dispersion Angle sector. The POA for that intersect is calculated as (15.7 * .1) = 1.6

Region B contains four unique intersects, combining to yield a POA of 4.9.

- The upper left quadrant covers 5% of the 75% annulus not covered by a Dispersion Angle sector (15.1 * .05 = .8 POA)
- The upper right quadrant covers 4% of the 95% annulus not covered by a Dispersion Angle sector (13.5 * .04 = .5 POA).
- The lower left quadrant covers 40% of the 75% annulus/95% sector intersect (4.8 * .4 = 1.9 POA)
- The lower right quadrant covers 30% of the 95% annulus/95% sector intersect (5.7 * .3 = 1.7 POA).

The examples in Figures 4, 5, and 6 use only two LPB factors and have been artificially simplified to illustrate the basic concepts. (Discussion of modeling nuances -- such as closing the Dispersion Angle POA at the 95% Distance from IPP radius -- are beyond the scope of this paper). Even with the simplification, the probability model is already complex enough so that the human math involved would be tedious as well as unreliable. For this reason, this methodology is best supported using a GIS system, or software specifically designed for this purpose, such as FIND, developed by dbS Productions, LLC (Koester, 2015).

As shown in Figure 2, once Subjective POAs and Objective POAs are obtained, they can be combined appropriately (averaged, then normalized) to derive Initial POAs for each Search Region. In our current approach, Subjective and Objective POAs are weighted equally. Depending upon the quality of information at a particular search incident, planners may choose an unequal weighting.

C. Making Probability Visual

In Washington State counties, the role of Incident Commander is typically filled by a Sheriff's Department deputy. We have learned through experience that the quickest way to lose the interest and "buy-in" from an Incident Commander is to present a 30-minute lecture on the complexities of computing probability based on the principles of modern search theory. For that reason, we rely on visualization of probability to quickly convey the results of our calculations in an easy-to-understand display. Figure 7 shows an example of this for the Muir Snowfield search.

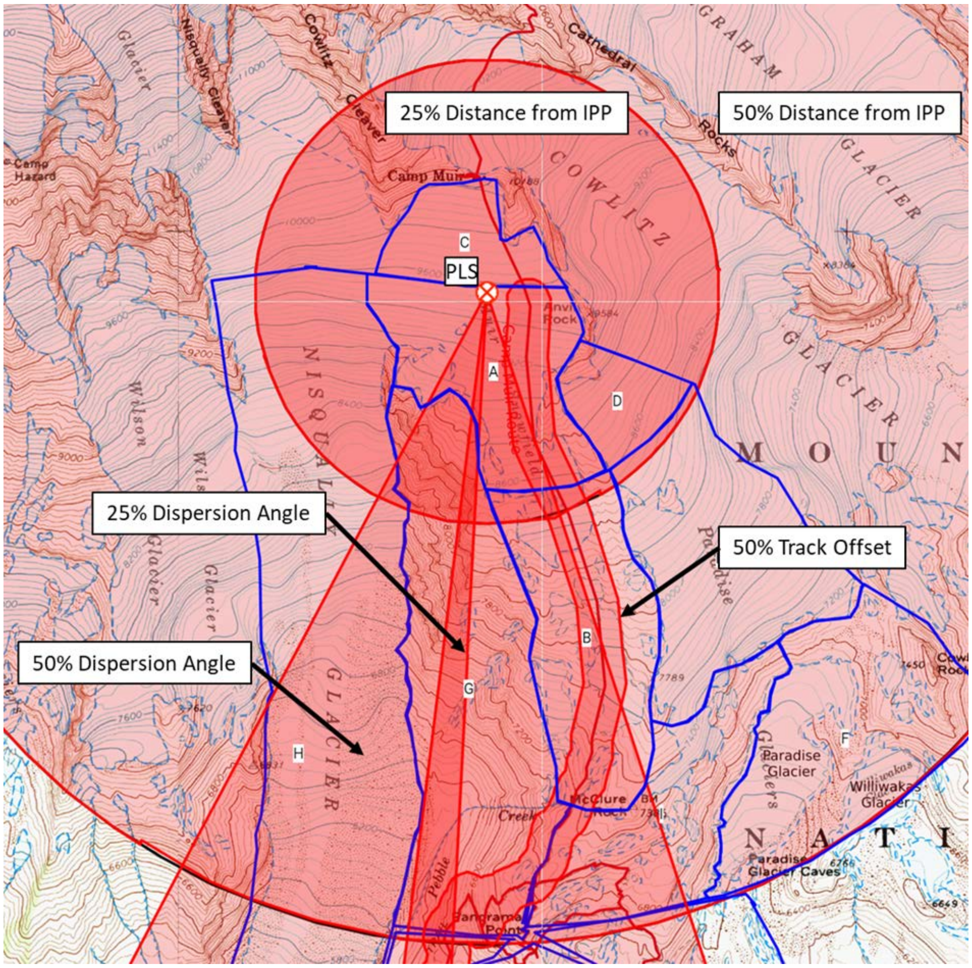

Figure 7: *Search Regions on a Shaded Probability Map*

In Figure 7, Search Regions are outlined in blue over a probability map (based on LPB factors Distance from IPP, Dispersion Angle, and Track Offset). The red shading in this figure represents Probability Density, but can be described to Incident Commanders simply by saying that "*darker areas indicate areas of higher probability*". This approach provides a quickly understandable picture of the logic behind the applied search theory. It also provides a cognitive picture of how probability can be related to statistical (historical) data from Lost Person Behavior.

A different example of visualizing Search Region probability is shown via "thermal color coding" in Figure 8 for the same Muir Snowfield search. To create this representation, Region POAs were divided by region area to derive a Probability Density (Pden) for each Search Region. The range of quantitative Pdens were then grouped into priority categories with an assigned "thermal" color code. This approach allows the Incident Commander and other non-technical search staff to quickly view relative priorities assigned to Search Regions.

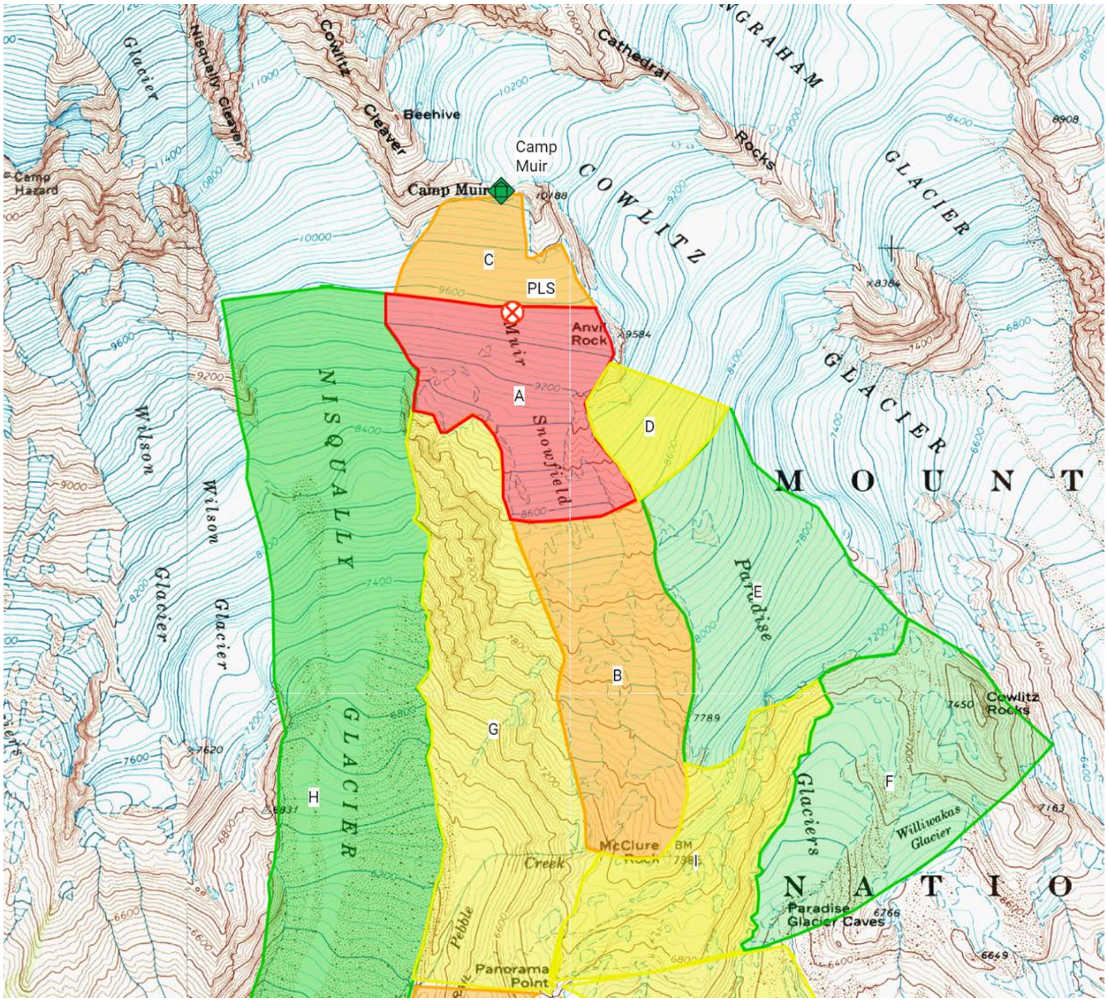

Figure 8: *Thermal Color-Coding of Search Region Priorities*

D. Characterizing Search Segments

Once Search Regions have been characterized, we employ a standard approach to defining and characterizing Search Segments, using terrain analysis and map-reading skills, and following the guidelines below (Hill, 1997; Stoffel, 2006):

- The size of a Search Segment should be such that a search team can reasonably cover their assigned segment in 4-6 hours. Teams should be able to complete their assignment, including travel to and from their assigned area, within one operational period. (Cooper, et al, 2003)

- Where possible, segment boundaries are defined using physical terrain features or manmade features, that are easy for teams to identify both on a map and in the field. Where terrain features are not available, contour lines are sometimes used as segment boundaries. We also use UTM grid boundaries, which are easy to identify on properly marked maps and easy to locate using handheld GPS devices. (In the field, we highly recommend downloading segment boundaries onto team GPS devices as a navigation aid).

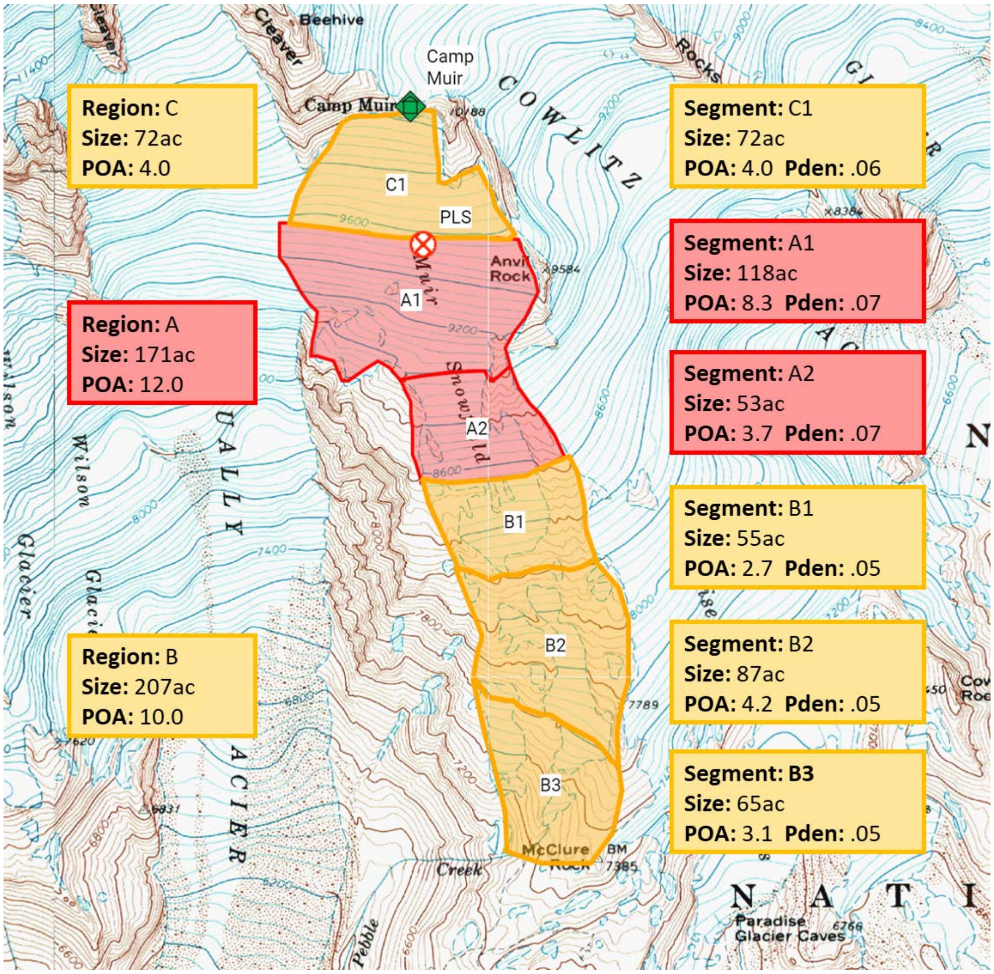

Figure 9: *Three Example Search Segments with Segment POA and Pden*

Figure 9 shows segmentation for three of the Search Regions defined for the Muir Snowfield Missing Snowshoer Search. In this example, Search Segments have been defined using both terrain features and elevation contour lines. After Search Segments have been defined and mapped, they inherit POA from their "parent" region, in proportion to their relative size within the region (Cooper and Frost, 2017). In other words, the POA of a segment is equal to the relative area of the segment (segment area divided by region area) times the POA of the region.

In Figure 9, Search Region sizes and POAs are shown in the left panels. Search Segment sizes, POA and Pden are shown in the right panels. From these, one can see that:

- The sum of segment POAs equals the POA of the parent region.
- Probability density (Pden) is distributed evenly among search segments in a given region.

II. Assessing Search Effectiveness

Our general approach to assessing the effectiveness and coverage of search teams is diagrammed in Figure 10, and is dependent upon the availability of data from earlier searching during the incident. When searchers are debriefed after their assignments, their reported data may be in either graphic form (drawn or recorded team tracks) or verbal form (descriptive information about their search behavior).

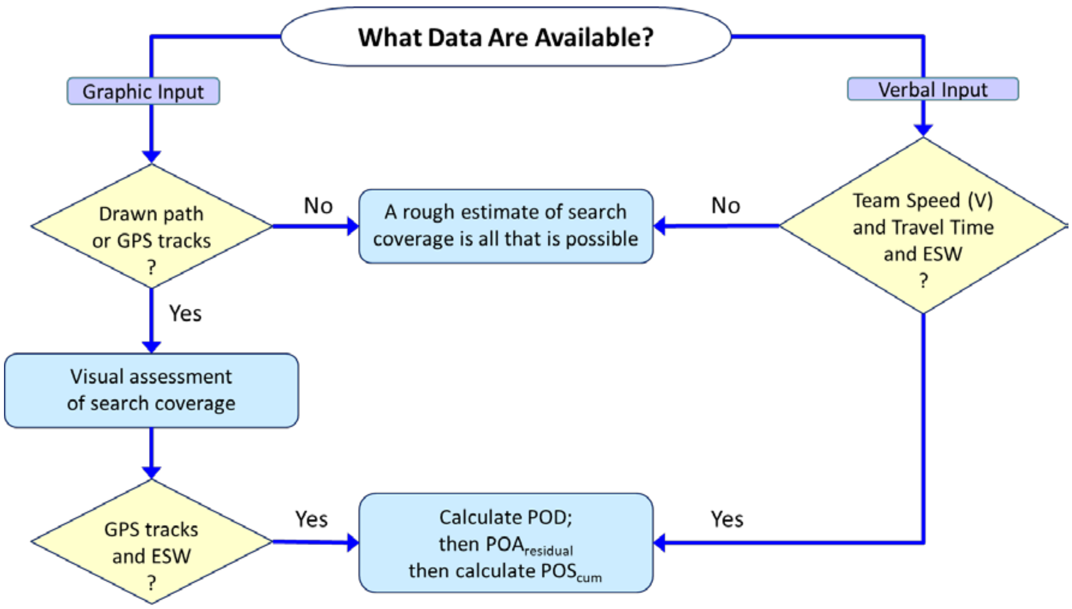

Figure 10: *Decision Guide for Assessing Search Effectiveness*

A. Assessing Search Effectiveness with Minimal Data

When the only search coverage information available is subjective, the choices are: (1) Ignore the information or (2) Use the information in a systematic way. We choose the latter. While it is widely agreed that subjective estimates of POD are considerably less than accurate (Frost, 2000), the following steps may be employed to reduce variability and error in those estimates: (a) Search teams should be debriefed in a structured manner with standardized questions about search conditions, searcher fatigue, distances traveled, areas covered, terrain, weather conditions, visibility, time of day, lighting, and foliage. (b) POD estimates should be based on a consensus of the entire team, rather than the estimate from a single person or the team lead. (Frost, 2000).

Even with the systematic steps described above, these subjective coverage estimates cannot be safely quantified as ratio or interval data. It may be acceptable to treat the results as ordinal data, for example by ranking coverage in search segments on a simple scale such as: High, Medium, Low.

This relative ranking can then be combined with other factors (e.g., new investigative information, found clues, etc.) to provide guidance about future search priorities.

B. Visual Assessment of Search Effectiveness

GPS tracking devices are gradually becoming standard equipment for search teams, and are now available in the form of handheld GPS units, GPS collars for K9s, and cellphone-based applications. With appropriate planning and technology, such tracks can become available in almost real time, to provide search effectiveness information during an operational period.

It is common in our experience that as we engage in a search, we find that GPS tracks from search teams are available (typically for many, but not all teams), but that no estimates of sweep width have been made. It is clear from the literature that it is not possible to calculate an objective POD without a measure of detectability (Frost, 2000). However, even without quantifying POD or coverage, the plotted tracks can provide important planning information. Figure 11 below shows GPS tracks captured via K9 collars (blue lines) and UAVs (yellow-dotted lines) during a search for a missing male in a rural environment, superimposed on an aerial map layer. During the search, this representation was used to understand which search segments had been searched by what search resources. Planners were also able to visualize a rough estimate of the portion of each segment traversed by a search asset.

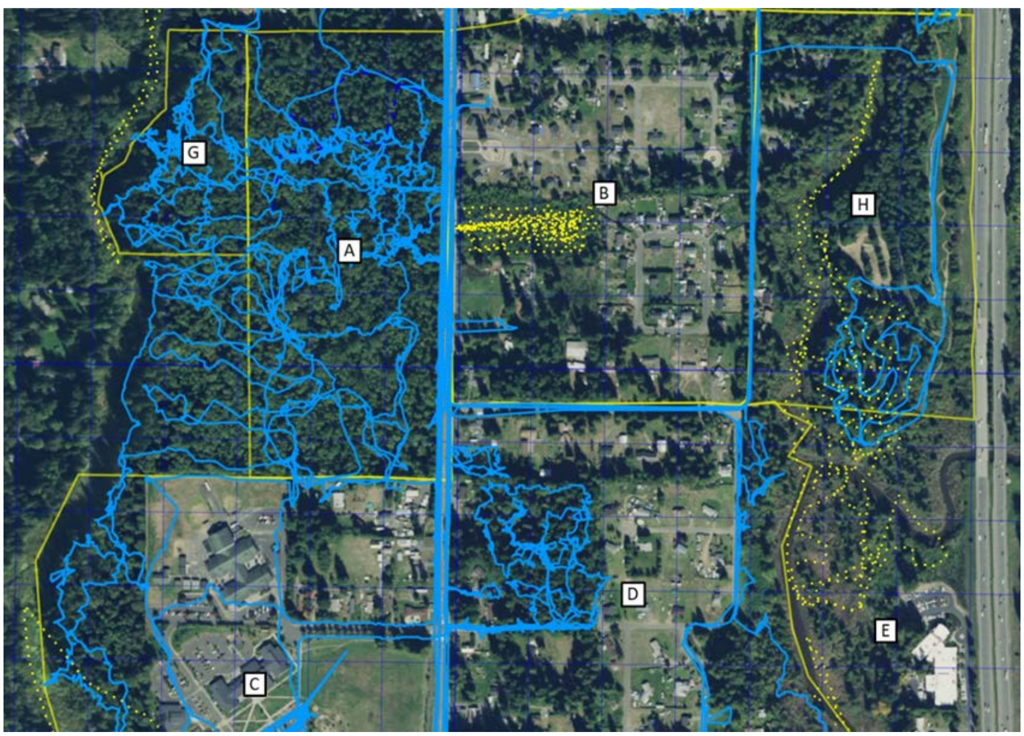

Figure 11: *K9 GPS Tracks (Blue) and UAV GPS Tracks (Yellow) from a Rural Search*

In Figure 11 for example, it can be seen that Segment A (about 40 acres or 0.16 km^2) has been generally well searched by airscent K9 teams. One exception that can be readily seen is the northern section of that segment. Segment A was immediately across the street from the PLS, and for that reason additional K9 resources could have been assigned to the northern section as a priority area. In the adjacent Segment B, it is apparent that there has been almost no K9 searching, and that one wooded lot has been extensively overflown by UAVs.

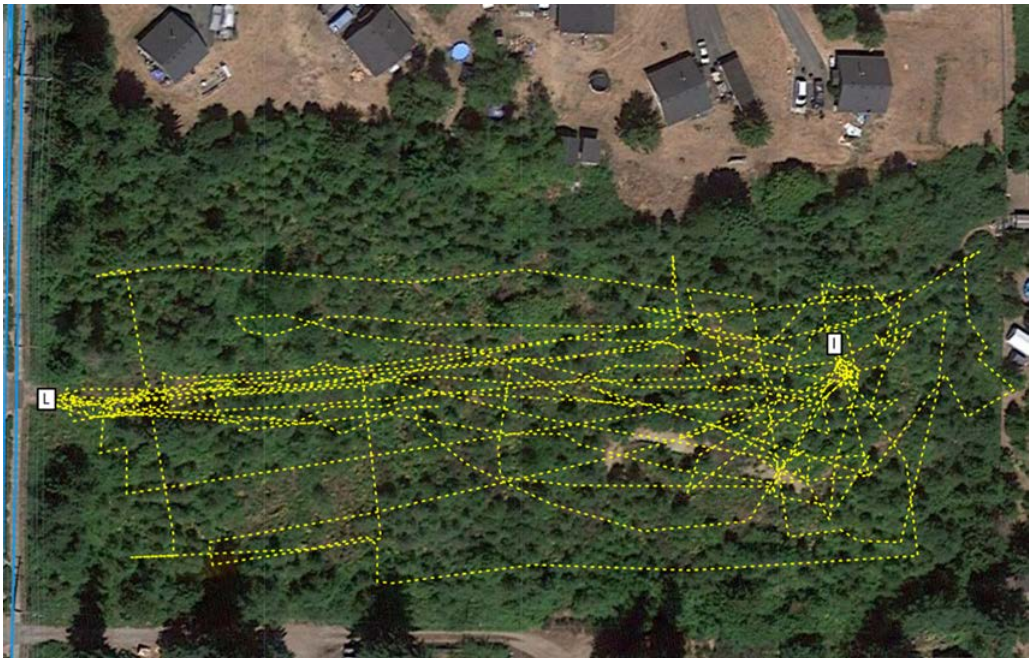

Figure 12: *Detail View of UAV GPS Tracks (Yellow) from a Rural Search*

Figure 12 shows a detail view of the small wooded area (5 ac, 0.02 km^2) in Segment B. In this figure, Point L indicates the UAV launch point and Point I was an object of interest. From this representation, planners could see that the UAVs flew a rough grid pattern, with relatively good "coverage" in central areas, but less "coverage" on the northern and southern edges. When team tracks are collected and plotted as the operational period progresses, teams assigned for future searching can be provided with these maps as an aid to understanding where they might want to focus their efforts.

The hypothetical table below illustrates how subjective, ordinal-scale assessment of coverage can be viewed systematically to help guide decisions about priorities for subsequent operational periods.

	Subjective Coverage Assessment			
Search Segment	**Ground**	**K9**	**UAV**	**Re-search Priority**
1	High	Medium	None	Medium
2	High	High	Medium	Low
3	Low	Medium	None	Medium

4	Low	None	Low	High

Table 2: *Hypothetical Example of Subjective Search Coverage Assessment*

While subjective, visual assessment of search coverage can serve as an important adjunct to relying solely on calculated POD (as described below). Using standard search theory math, POD increases as a factor of Track Line Length (TLL), independent of where the search team has traveled within a segment. As shown in Figure 13 below, the TLL, Estimated Sweep Width (ESW) and calculated POD for each segment is the same; however, a visual assessment reveals important additional information about the effectiveness of the search and considerations for re-search.

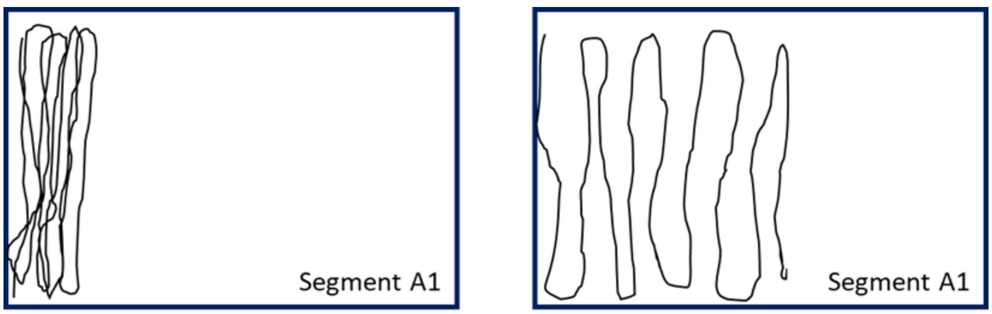

Figure 13: *Two Searches with Equal TLL, ESW, and Calculated POD*

C. Calculating Coverage When Estimated Sweep Width Is Available

In the lower left of Figure 10, we can see that if GPS tracks (which provide TLL) and Estimated Sweep Width are available, standard search theory math can be used to calculate POD, residual POA, and POS values for each search segment. We can also see from the right side of Figure 10 that if search teams can provide travel speed and travel time (used to derive TLL), as well as ESW, then POD calculations can also be done. Based on this, our recommended best practice for search teams is to perform an Average Range of Detection (AROD) exercise prior to initiating their assignment, and to record GPS tracks while performing their search. When this is done, planners have the advantage of being able to both visually assess search patterns and to calculate POD.

III. Prioritizing Search Assignments

Once Search Segments have been defined and characterized (i.e., with POA and Pden), search theory methods should be used to guide applying resources to assignments (Cooper, 2015). This can be done for the first operational period (where sweep width and team speed would be estimated prior to assignment), or for subsequent operational periods (where sweep width would be estimated and team speed and travel may be available via GPS tracks). In either case, the preferred methodology would be to prioritize search assignments based on calculated Probable Success Rate (PSR).

Figure 14 shows a decision guide for using available data to prioritize Search Segments. Where all necessary data (POA, Area, ESW, Team Speed) are available, we calculate PSR and use that to guide prioritization of search assignments. Where only POA and Segment Area are available, Pden can be used to guide assignment priorities; however, consideration should be given to estimating ESW and Team Speed, thereby allowing use of PSR calculations.

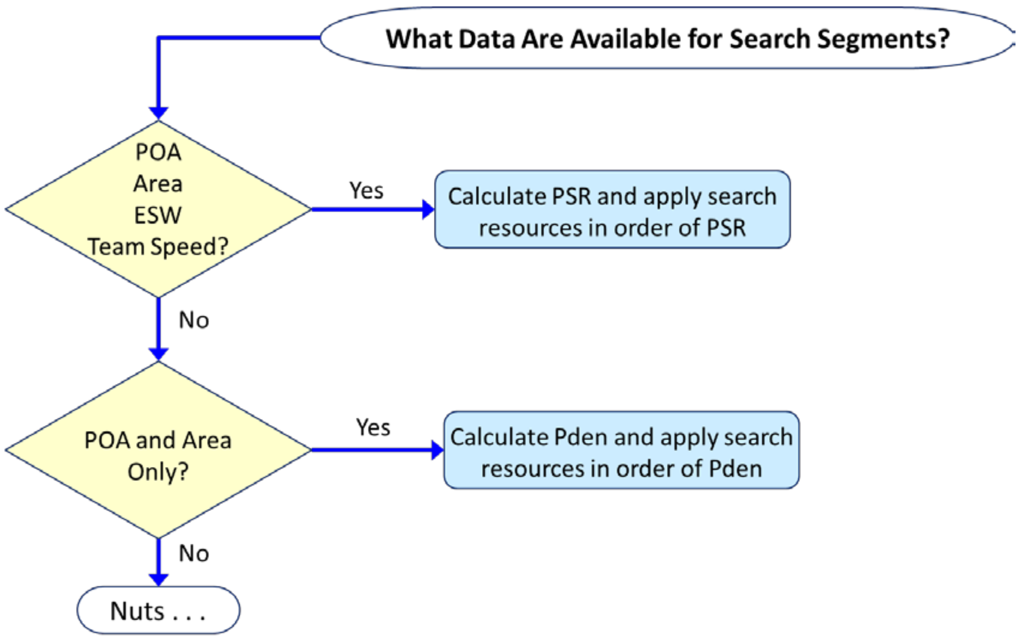

Figure 14: *Decision Guide for Using Available Data to Prioritize Search Segments*

It is important to note that a more holistic approach to prioritizing search assignments would be to systematically consider three factors:

- Probable Success Rate – calculated prior to each operational period.
- Visual assessment of search team tracks in each search segment.
- Quantity and nature of any clues found in each search segment.

IV. Special Considerations

A. Characterizing Search Regions with Multiple Scenarios

In our experience, search planning typically begins with identifying multiple possible scenarios for what has happened to our lost subject. When multiple scenarios are in play, Frost and Cooper, (2014) recommend that consensus-based POAs for each Search Region should first be derived independently, then subsequently combined (using a weighted average) to yield a "composite" subjective POA for each region. This approach imposes additional calculation overhead; however, it should be noted that the National SAR School makes a spreadsheet available for supporting these calculations. In the spirit of full disclosure, we currently do not use these multiple, independent POA estimates. We rely on the knowledge and experience of the individual contributors to subjectively weigh the relative contributions of each scenario.

B. Relocating the IPP, LKP, or PLS Based on New Information

A recent search in the Cascade Mountains of Washington State began with the discovery of the subject's car parked at the trailhead. This location was used as the IPP and LKP. As in many searches, more information became available as the search proceeded – in this case, multiple, reliable sightings of the subject were reported by hikers on the same trail. For the purpose of characterizing Search Regions and Segments as described in Section I above, should the analysis of scenarios, range rings, dispersion angles, subjective and objective POAs be re-positioned and focused around the new (revised) LKP? We believe that based on logic and on discussions at the 2018 Syrotuck Symposium, that the answer is "yes". Koester has suggested (based on limited data) that a repositioned LKP might allow planners to reduce LPB "Distance from IPP" values by as much as 20% (Koester, 2018).

C. Practical Issues Related to Obtaining Estimated Sweep Width

In the ideal search world, AROD estimates are performed by search teams after they have entered their assigned search segment and before they start their search assignment. In a more typical, but less ideal search world, teams do not perform AROD estimates prior to their search. One way to address this would be to send out personnel either during or after the search to perform AROD estimates in representative areas.

When a search is being planned in advance, search personnel can be sent out to get AROD estimates in the search area prior to the operational period. A potentially very useful variant of this approach is to pre-establish AROD estimates for representative search areas within a local jurisdiction. This would yield a table like the example below with pre-assessed AROD values for different types of terrain. This approach is currently being incorporated into the FIND Software Project (Koester, 2018).

Terrain Category	Target Type	Day or Night	AROD (meters)
Second growth forest – light undergrowth	Human Size	Day	5
Second growth forest – light undergrowth	Human Size	Night	3
Second growth forest – moderate undergrowth	Human Size	Day	3
Second growth forest – moderate undergrowth	Human Size	Night	1
Second growth forest – heavy undergrowth	Human Size	Day	1
Second growth forest – heavy undergrowth	Human Size	Night	.5
Second growth forest – light undergrowth	Small Object	Day	2
Second growth forest – light undergrowth	Small Object	Night	.5

Second growth forest – moderate undergrowth	Small Object	Day	.5
Second growth forest – moderate undergrowth	Small Object	Night	.2
Second growth forest – heavy undergrowth	Small Object	Day	.2
Second growth forest – heavy undergrowth	Small Object	Night	.1

Table 3: *Hypothetical Pre-Assessed AROD Values for a Variety of Terrain Categories*

Without going into details, it does need to be pointed out that obtaining useable ESWs for K9 search resources and UAV resources remains largely unaddressed. For UAV resources, it should be theoretically feasible to set up the equivalent of an AROD estimate process, or to pre-estimate ESWs for terrain categories as described above.

On a final, practical note, it seems that one feasible approach would be to estimate AROD (for whatever search resource is applicable), based on a "reasonable guess". The weakness of this approach is that it does not support a calculation of <u>absolute</u> coverage. However, if used consistently across search segment calculations, an estimated ESW will still yield a usable <u>relative</u> coverage value for assessing search effectiveness among search segments in similar terrain.

Discussion

Our goal in documenting a pragmatic approach to applied search theory is to provide the foundation for a step-by-step guide for the Washington State SAR Planning Unit for what components of modern land search theory can be used for planning search incidents in jurisdictions that may vary widely in terrain, data availability, and training. This planning decision guide, along with associated templates, spreadsheets, and computer software, will form the basis of a standardized search planning approach which can be taught to members of SSPU and implemented by them for future incidents.

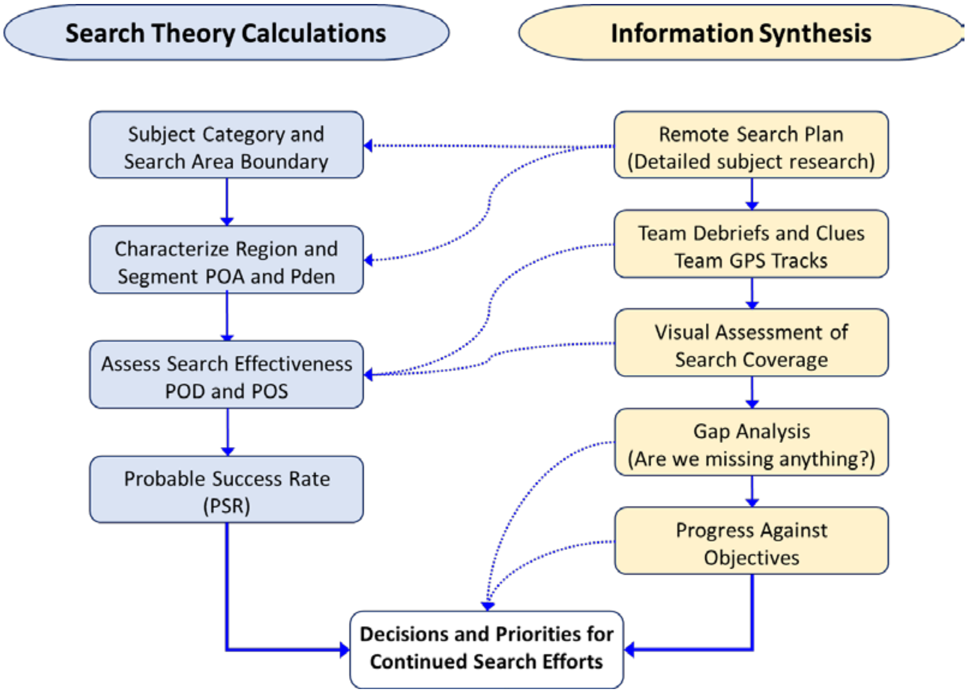

Figure 15: *An Overview of Integrated Search Planning*

Figure 15 above, provides an overview of how components of formal search theory can be combined with information synthesis, research, and situational analysis (Burke, 2019; Wright and Smith, 2019; Young, 2019) to provide a more comprehensive basis for the decisions and priorities used to guide continued search efforts. When data are available, the SSPU will use search theory best practices, concepts, and calculations to provide objective, probability-based input to search planning. These will be augmented in parallel with detailed research (i.e., Remote Search Plans), and systematic collection and analysis of other available information.

Conclusion

Our pragmatic approach to applied search theory, as described above, is in the early stages of being implemented as standard search planning methodology employed by the Washington State SAR Planning Unit. We will be using this approach, supported by the decision guides and associated tools, as a basis for training our members and supporting search incidents. We anticipate gaining practical experience with these methods as they are applied in the real world of land searches, and plan to provide a future report detailing which approaches work well and which would benefit from improvement.

Acknowledgements

We would like to acknowledge the invaluable input and feedback provided to us by Dr Donald Cooper and Dr Robert Koester during preparation of our methodology and of this manuscript. In addition, we would like to thank all organizers and participants of the 2018 Syrotuck Symposium, held in Reykjavik, Iceland – your encouragement and support is greatly appreciated. We are indebted to our SAR County Coordinators, Sergeant Danny Wikstrom (Snohomish County Sheriff's Department), and Detective Ed Christian (King County Sheriff's Department), for their years of guidance while we gained experience as Incident Command staff. Lastly, a special thanks to Chris Long of Washington State Emergency Management Division and to Jon Wartes of King County Search and Rescue for their foresight and encouragement. Maps in this paper were created using SARTopo, www.sartopo.com.

About the Authors

Guy Mansfield is a Director of the Washington State SAR Planning Unit. He has been a SAR volunteer since 2008; has been a member of the Mountain Rescue Association; and has served as Planning or Operations Section Chief on some of the largest search incidents in recent Washington State history.

Joe Carlson is a member of the Washington State SAR Planning Unit. He has been active in SAR since 2007.

Danny Merrifield is on the leadership team of the Washington State SAR Planning Unit. He has been active in SAR since 2011; is currently a member of Mountain Rescue Association; and has served as Planning or Operations Section Chief on numerous SAR missions.

Eric Rosenberg is a Director of the Washington State SAR Planning Unit. He has a degree in Geography and has been a SAR volunteer since 1999. He has served on over 500 missions – as Planning or Operations Section Chief on half of these.

Erik Swanson is a member of the Washington State SAR Planning Unit. He has been active in King County Search and Rescue since 2011, serving both in the field and as Planning or Operations Section Chief.

Peter Templin is a member of the Washington State SAR Planning Unit. He has been a SAR volunteer since 2014, supporting in both Operations and Planning roles.

Abbreviations

AROD	Average Range of Detection
ESW	Estimated Sweep Width
GIS	Geographic Information System
GPS	Global Positioning System (can also refer to a handheld GPS device)
IPP	Initial Planning Point
ISRID	International Search and Rescue Incident Database
LKP	Last Known Point
LPB	Lost Person Behavior (Koester, 2008)
Pden	Probability Density
PLS	Point Last Seen
POA	Probability of Area
POD	Probability of Detection
POS	Probability of Success
PSR	Probable Success Rate
ROW	“Rest of the World” (area outside the formal search area boundary)
SSPU	Washington State SAR Planning Unit
TLL	Track Line Length
UAV	Unmanned Aerial Vehicle (a.k.a. “search drone”)
UTM	Universal Transverse Mercator

References

Burke, P. M. (2017) *Virtual Search Planning*. Retrieved from https://www.virtualsearch.me/

Burke, P.M. (2020) Virtual Search Planning. *Journal of Search and Rescue*, 4(1), 4-5. http://journalofsar.com.

Cooper, D.C. and Frost, J.R. (2017) *Selected Inland Search Definitions*. Unpublished Document.

Cooper, D.C., Frost, J.R., Robe, Q.R. (2003) *Compatibility of Land SAR Procedures with Search Theory*. Potomac Management Group Inc.

Department of Homeland Security (2011) *Land Search and Rescue Addendum to the National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual Version 1.0*.

Frost, J.R. (2000) Principles of Search Theory – Part I: Detection*. Response*, *17(2) 1-7.*

Frost, J.R. and Cooper D.C. (2014) *Proportion-Based Consensus – Establishing Initial POA Values*. Unpublished Document.

Hill, K. (1997). *Managing Lost Person Incidents*. Chantilly, Virginia: National Association for Search and Rescue.

International Maritime Organization and International Civil Aviation Organization (IMO/ICAO). (1999b). *International Aeronautical and Maritime Search and Rescue Manual: Vol. II. Mission Co-ordination*. London/Montreal: the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO).

Jacobs, M. (2016) *Terrain Based Probability Models for SAR*. http://mra.org/wp-content/uploads/2016/05/TerrainProbabilityModelsReport.pdf

Koester, B.K. (2008) *Lost Person Behavior: A Search and Rescue Guide on Where to Look – for Land, Air, Water*. dbS Productions LLC, Charlottesville, Virginia. www.dbs-sar.com

Koester, R.J., Chiacchia, K.B., Twardy, C.R., Cooper, D.C., Frost, J.R. and Robe, Q.R. (2014) Use of the Visual Range of Detection to Estimate Effective Sweep Width for Land Search and Rescue Based on 10 Detection Experiments in North America. *Wilderness & Environmental Medicine*, 25, 132-142.

Koester, R. J. (2015). dbS Productions - The Source of Search and Rescue Research, Publications, and Training. http://www.dbs-sar.com/

Koester, R.J. (2016) *Endangered & Vulnerable Adults and Children: Search and Rescue Field Operations Guide for Law Enforcement.* Land Search and Rescue Manual Vol. VI. dbS Productions LLC, Charlottesville, Virginia. www.dbs-sar.com

Koester, R.J. (2020) Enhancements to Statistical Probability of Area Models Based upon Updated ISRID Data Collection for Autism Spectrum Disorders and Typical Children. *Journal of Search and Rescue*, 4(1), 65-83. http://journalofsar.com.

Koester, R.J. (2018) *FIND Software Project Update*, 2018 WASAR Conference, Ellensburg, WA.

Stoffel, R.C. (2006) *The Handbook for Managing Land Search Operations.* ERI Publications.

Wright, S. and Smith, R. (2020) The SAR Planning P Process – A Framework for Transitioning from Initial Response to Extended Operations. *Journal of Search and Rescue*, 4(1) 111-135. http://journalofsar.com.

Young, C.S. (2020) The Search Intelligence Process. *Journal of Search and Rescue*, 4(1) 136-164. http://journalofsar.com.