Interpreting Negative Search Results

J. R. Frost

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According to most estimates, 90-95% of all SAR incidents are resolved in the first operational period—often within a few hours. When any searching at all is required, "hasty searches" usually succeed. However, when hasty and other rapid techniques do not produce success quickly, finding subjects in time to save their lives becomes a considerably more difficult challenge. Unfortunately, some catastrophic failures have occurred where subjects were not found in time despite massive and timely commitment of resources.

Consider the following actual incident: A despondent mother of two, under treatment (including medication) for depression, fails to attend a therapy session one morning. The alarm is raised and her car is located in a nearby wilderness area that same afternoon. A massive four-day search ensues and expands over that time to cover several square miles. Her remains are eventually located, essentially by accident, in heavy brush about 100 yards from where her car was parked. She had ingested an overdose of her medications, apparently on the first day, and died as a result. Why did it take so long to find the subject in spite of her proximity to her last known position (the car)?

This case is not unique. Similar cases have occurred where it seems (not necessarily despondent) subjects should have been located much earlier than they were given the number of resources employed. In fact, there have been enough such incidents to indicate a systemic problem may exist. In some the subject was found still in reasonably good condition. In other cases subjects

were found barely in time to prevent a tragedy. Of greatest concern are those cases where subjects died from exposure or lack of timely treatment for illness or injury. Let's examine some assertions about the conduct of searches that are found in popular land SAR texts and articles to assess their potential for encouraging practices that leave the subject in danger longer than necessary and thereby increase the potential for tragedy.

1. Assertion: Once a segment (sector) is searched (regardless of how high or low the coverage), it should go to the bottom of the "priority" list for further searching (Perkins & Roberts, 1994).

Placing segments in a "circular queue"—like children repeatedly taking turns on a slide—is ***NEVER*** the correct way to allocate resources over time (see Koopman [1946, 1999], Charnes & Cooper [1958], Stone [1989], Washburn [2002]). Note that this method promotes a philosophy of, "Search everywhere once before searching anywhere twice." A segment given an initial cursory search that missed the subject even though he or she was there might take a very long time to percolate back up to the top of the list where it would be eligible for a second search. Meanwhile the subject's location would remain unknown and he or she would remain in danger without potentially life-saving assistance. This method of "prioritizing" segments is overly simplistic and may substantially delay finding the subject. Correct methods exist for optimally allocating resources so the time it takes to find subjects is minimized. None of them advocate use of a circular queue or any modification thereof. Optimal resource allocation methods are beyond the scope of this article, but they are well documented in the scientific literature and are widely used with great success outside of land SAR—where they have not yet been applied.

2. Assertion: Subjects leave behind so many clues that even a low coverage search will rarely miss all of them; therefore one may almost always conclude that the failure to find any clues means the subject was never there (Hill, 1995 & 1997).

This line of reasoning is completely ***FALSE*** because it depends on a false premise. It is a misapplication of a result from information theory (a mathematical approach to improving digital communications) that assumes the clues ***do not*** have a common source (we know they do—it's the subject) and that the clues are uniformly distributed over the segment's area (we know they are not—they are only in a narrow swath along the subject's [unknown] track, which is what makes tracking possible once clues are found). The actual potential for making that first discovery of a clue under typical conditions, even when several clues are present, is only slightly better than that for discovering a single clue if only one is in the segment. The original assertion that it is virtually impossible to miss all the clues when several are present leads to a dangerously false sense of confidence about where the subject is not located based on negative results from low coverage searching. Like the first assertion involving use of a circular queue to "prioritize" segments, it can encourage a search manager to prematurely abandon a segment in favor of unsearched segments that may have even less potential for producing a successful outcome than a second search of the just-completed segment would have. It is also worth noting that the mathematical principle on which the above assertion is based does not involve any kind of searching. The actual context is computing the odds that at least one data bit in a string of ***n*** bits transmitted through a channel with "white noise" (e.g., static) will "take a hit" and be changed from a 0 to a 1 or vice versa before it is received (see Hamming [1980]).

3. Assertion: If the perimeter of a segment is searched without finding any evidence of the subject's entry or exit, it is safe to conclude the subject is not/has not been in the segment (Stoffel, 2001; Hill, 1997; LaValla et al., 1997).

This technique, sometimes referred to as "sign cutting" by trackers, has been suggested for use in so-called "binary searches" to eliminate segments from consideration without actually searching them. "Binary search" is a technique commonly used in computer programming to quickly either find an item in a sorted list of items or confirm that it is not present (see Knuth [1998]). For example, if one is searching for a particular name in a telephone directory, one could open the directory in the middle, determine whether the name was in the first or second half of the directory, then look in the middle of the appropriate half, and repeat the process until the page where the name should appear is found. Note that at each step, half the remaining pages are eliminated. The SAR version of "binary search" is based on the tacit but ***FALSE*** premise that the search for sign (small, discoverable evidence of a subject's passing) is always 100% effective. Unlike searching for a specific name in a telephone directory, being "discoverable" does not mean actual discovery of a clue is guaranteed when it is present. Since sign is usually very difficult to detect and is therefore easily missed, the very premise on which binary search is based cannot be true. Thus, the use of a binary search is rarely, if ever, justified. This is another example of applying a mathematical concept outside a context in which it is valid. Both the information theory assertion and the binary search assertion are based on mathematics for linear situations (strings of data bits and linear lists respectively) and special preconditions ("white noise" that provide complete statistical independence among "hits" in a string of data bits, and

pre-sorting of linear lists respectively) that have no valid analogs with searching for clues over some geographic area.

4. Assertion: Two successive low coverage searches produce a higher cumulative probability of detection (POD) than a single search when both methods consume the same total number of searcher-hours (Stoffel, 2001; Hill, 1997; LaValla et al., 1997).

This is a ***FALSE*** statement (see Koopman [1946, 1999], Stone [1989], Washburn [2002]). It is often incorrectly used to imply that early investment of moderate to high levels of effort in a segment is never justified. Two successive searches can do no better than equal the POD from applying all the effort in a single search, and they can easily do worse if not carefully done to minimize overlap with previous searching.

Taken together, these four highly questionable assertions offered as guideposts for search managers all point in one direction: Do quick searches with thinly spread resources and then move on if unsuccessful. They encourage extended searches that are just repetitions of initial response techniques over larger and larger areas that consume additional resources as fast as they become available. They discourage expending even some of these resources on more thorough methods or re-searching segments, even when such use is more likely to produce success than expansion. All of this is exacerbated by subjective POD estimates for rapid search techniques that are often unrealistically high. As recent detection experiments have demonstrated, even the best searcher is capable of walking past a very obvious clue or even a clearly visible but

unresponsive subject at close range without making a detection. No sensor is infallible, including human searchers.

So, why are hasty searching, sign cutting and rapid searches with thinly spread resources in the early hours so often successful and therefore highly recommended? There are two reasons: First, these methods are the fastest way to resolve the situation when subjects are easy to find—which they are in most cases. Second, the importance and informational value of a quick positive result (finding a clue or the subject) is so high that rapid techniques are worthwhile gambles early on when resources are scarce, clues are still fresh, and the subject is most likely to be responsive and therefore more detectable.

On the other hand, as soon as it becomes apparent the subject is not going to be so easy to find, these rapid response methods start to lose their value. Despite their "rapid" nature, their continued application under a purely "expansionist" policy can actually delay finding the subject in many cases. Search managers need to think really hard about whether to re-search some or all the segments already checked by rapid methods, expand the search beyond those segments, or do some of each. Under a true optimal effort allocation strategy, the last alternative is almost always the best, and when it is not, the correct answer is not to expand but to re-search the segments searched so far.

It is important to understand that a negative result from a single cursory search often provides almost no information about where the subject either is or is not. Failing to recognize the profound difference in informational value between positive and negative results from rapid,

limited-resource methods is a trap that can lead to catastrophe. In short, positive results may tell us a great deal while negative results may tell us next to nothing. If search managers and planners automatically assume that it is always better to expand into unsearched segments rather than go back and do a more thorough job in segments that were given only a quick "once-over" during the initial response, they are taking a very, very serious risk.

The following guidance for search managers and planners is recommended: Continue to use rapid methods (hasty searching, sign cutting, etc.) ***initially*** to see whether something can be found quickly that will help resolve the case earlier rather than later. However, if success is not achieved by these initial "quick-look" efforts, be extremely cautious about drawing conclusions based on their failure to discover any clues. Do not just automatically continue expanding to cover "new ground" with these same techniques while indefinitely postponing additional searching in those segments that have been examined only lightly. Instead, carefully re-assess the entire picture while maintaining due regard for the very real possibility that the initial quick looks could have missed important clues. Then assign the available resources accordingly.

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J. R. Frost Biographical Info:

Mr. Frost has been involved in international aeronautical and maritime search and rescue for more than 30 years, including 23 years on active duty as a U. S. Coast Guard officer. Duties included being a Rescue Coordination Center (RCC) controller, the senior systems analyst for the USCG's Computer Assisted Search Planning (CASP) system and Commanding Officer of the USCG's Operations Computer Center. He holds a B.S. in Mathematics from Florida State University and a M.S. in Computer Science from the Naval Postgraduate School. He has studied search theory for much of the last 30 years and works with world-leading experts in this area, including Dr. L. D. Stone, author of the award-winning book *Theory of Optimal Search*. Mr. Frost's post-graduate work included study of Information Theory under the late Dr. R. W. Hamming, developer of the well-known "Hamming codes" for detecting and correcting errors in digital messages transmitted through "noisy" channels. For the last seven years, Mr. Frost has made a careful study of manuals and articles that provide guidance to land search managers and search planners. He has compared their contents to the considerable body of scientific literature on the subjects of search and search theory and found substantial shortcomings in the land SAR literature. The article submitted above is an attempt to correct some of the more important misperceptions found in many corners of the land search community today. Mr. Frost is currently employed by the USCG Office of Search and Rescue in Washington, DC, as an expert on search planning methods and systems.