Second Draft
For Review & Comment

<u>Author's Note:</u> In the interest of fairness and to ensure no misrepresentation of Maritime SAR methods, J.R. Frost's comments and suggested revisions are included in their entirety. For this reason, the pagination from the original posting is no longer valid. Any disagreements or further "comments on the comments," will be reserved for the Third Draft. The Author gratefully acknowledges Mr. Frost's close reading of the Second Draft and his time and effort in annotating the text.

Controversial Topics In Inland SAR Planning

A NEWSAR White Paper
February 2004
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NEWSAR
[With Clarifications and Rebuttals by J. R. Frost]

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Overview

[JRF – The first word in the title of this paper, "Controversial," should be considered a misnomer. Search theory and its practical application to a wide variety of search problems are not at all controversial but quite well established around the world. In fact, to perhaps make a bad pun, the "rest of the world" outside of land SAR follows basic search theory principles when presented with a search problem. The only reason land SAR is different, in my opinion, is that the initial attempts to apply search theory were incomplete and piecemeal owing to a lack of adequate support for the necessary research and development work.]

Inland Search & Rescue Planning is, in some quarters, experiencing a crisis of confidence. Strident voices in the extended SAR community are calling for Inland SAR planners to abandon traditional techniques and adopt wholesale, the methods of Maritime SAR.

[JRF – I cannot speak to the first assertion, but the second assertion is absolutely false if it refers to our position. It is unclear what is meant by "methods of Maritime SAR." It could refer to the application of search theory to maritime SAR search planning and evaluation, or it could refer to search tactics typically used to search areas of ocean. In the first instance, the approach we advocate is the correct application of search theory to land SAR. The fact that search theory has already been successfully applied to maritime SAR is not a valid argument that it cannot be successfully applied to land SAR just because there are significant practical differences between the land and maritime operating environments. Most people would argue the opposite—success in one venue should bode well for success with the same type of problem (SAR searches in our case) in a different venue, provided due consideration is given to pertinent differences between the two venues. The alternative interpretation, that the exclusive use of maritime search tactics is being advocated for land SAR, is flatly incorrect.]

[JRF – Some statements in published land SAR "manuals" that are allegedly based on scientific search theory are, in fact, quite incorrect—separate and apart from any similarities or differences between land and maritime SAR. Since important decisions seem to be based on these statements from time to time, it seems this should be of grave concern. Unfortunately, one source of this disturbing information happens to be someone from a maritime SAR background, causing some to jump to the conclusion that the problem is not errors in the application of search theory to land SAR but an attempt to transfer maritime-specific tactics to land SAR when they are not appropriate. This is a very serious misunderstanding of our position that can be corrected only if our proposals are actually read and studied for their content.]

[JRF – What has actually happened is that we have taken a professional analyst's approach. We first studied the manuals and various other documents, including primary sources, that describe methods for planning and conducting land searches. We then interviewed a number of land SAR practitioners to document the issues facing land searchers, planners and managers as a means to further our understanding of the land search problem. We then went all the way back to the very basics of scientific search theory ***before*** it is applied to any particular type of search problem. Finally, we asked whether the assertions in these documents and the practices in the field were consistent with all the scientific research that has been done on "*…the operation of search as an organic whole having a structure of its own—more than the sum of its parts.*" (Koopman, [8]) The answer for area searches (as opposed to hasty searches, etc.) was, "No, not only in the way the mathematics is being applied, but more importantly there are fundamental conceptual flaws and omissions that have significant potential for leading to poor decisions in the field (through no fault of the decision-makers given their training), regardless of whether any computations are done."

[JRF – I first became involved with land SAR in 1997 as a result of writing Mr. R. Goodman (then the SAR Coordinator for New Mexico) about his article "The POC Factor" where "POC" stood for "probability of coverage." The article had been referred to me by a Coast Guard colleague who was also a member of NASAR. I explained to Mr. Goodman that he seemed to be grasping for the concept of "coverage," which is not a probability at all but it is closely related to POD. I sent him a document I had recently written for the maritime community explaining how their methods were derived from scientific search theory. All maritime search planners understood the maritime search planning procedures given in the manuals, but almost none had any idea how those procedures had been developed in the first place or that they were based on good science. Therefore, I developed an "information paper" for the maritime SAR community to show the connections between the basic theory and the "best practices" found in the manuals. Mr. Goodman took the document (he told me later) to the scientists at Sandia National Laboratories in Albuquerque, New Mexico, to ask them whether the document was scientifically valid. They responded that it was. Mr. Goodman then referred me to Mr. (now Dr.) D. Cooper who was at first incredulous, but willing to listen. Dr. Cooper asked me to meet him in Richmond at the NASAR conference that year, which I did. As a result of that meeting I began a study of land SAR search planning issues and techniques. I quickly discovered that the terminology, methods, and issues of land SAR were quite different from those with which I was familiar. It took quite some time and a lot of tutoring from land SAR search managers and authors to understand land SAR search planning and search execution techniques at a basic level. It then became clear that some statements in published land SAR "manuals" that were supposed to be based on search theory were incorrect and/or misleading.]

[JRF – From that point forward the goal has been to correct the errors and help the land SAR community to properly apply search theory to land SAR search planning problems whenever such application would be useful (which is far from every SAR response). The proponents of this approach are sufficiently sophisticated to see the differences between maritime and land SAR, contrary to the tone of this "white paper." Likewise, the suggestion that they want to force maritime-specific tactics on to the land SAR community seems to be present only for its inflammatory value. In fact, the direct transfer of maritime tactics to land SAR has never been under consideration. However, the same underlying science does apply in both arenas, even though the details of how that science is applied in practice will, of necessity, be different.]

The argument for this abrupt transition generally goes as follows: Maritime or Marine SAR (MSAR) is based on sound mathematical footing, dating back to Bernard Koopman's virtual invention of Search Theory during World War II. MSAR is a sophisticated sub-field of the broader discipline of Operations Research, while Inland SAR (ISAR) planning, as traditionally taught, is a makeshift assembly that is "unscientific."

[JRF – The transition only seems abrupt because the previous attempts at applying search theory to land SAR have taken some unfortunate turns. The objective is merely to make appropriate corrections to one very important but relatively infrequently used aspect of land SAR—the planning of searches over significant areas. Although the results of these corrections will affect the way search managers think about all searches and search techniques, in all likelihood there will be relatively little change in the details of the search activities themselves. The primary changes will be mostly in how probability regions are established and assigned POA values, how effort/resources are allocated across the search segments, and how search results are evaluated, as opposed to how searching is done within the segments after effort/resources have been allocated to them. Things like segmentation rules, for example, will remain relatively unchanged, but they will "inherit" their POA values (prorated on area) from the probability regions that were established and assigned POAs on the basis of lost person behavior statistics and other factors familiar to land SAR search managers.]

While it is not in the scope of this brief paper to recount the evolution of ISAR methods, we argue that far from being "makeshift," classic ISAR is a creature in the family tree spawned by Koopman, an adaptation, filling a "niche" as it were, to situations and conditions not encountered in the marine environment. This is not to say that ISAR cannot learn from its more sophisticated cousin. It can indeed, and should embrace MSAR methods when they are appropriate.

[JRF –When the evolution of "ISAR" attempts to apply search theory to land SAR is carefully studied, it is clear that these attempts really have been unscientific, and prone to significant conceptual, technical and even mathematical errors. In general, scientists did not develop the ISAR methods and scientific rigor was not applied, either initially or afterwards to confirm correctness. Those few individuals that did have academic credentials (i.e., Ph.D.) were working outside of their fields when it came to applied search theory.]

[JRF – It is incorrect and extremely misleading to refer to the version of "search theory" or the search planning methods of land SAR as being "spawned by Koopman." Were Dr. Koopman still alive, I am confident he would be the first to tell the land SAR community exactly the same kinds of things I've been trying to get across.]

[JRF – The concept of "effective sweep width" or "detectability index" is central to Koopman's work, but is nowhere to be found in land "search theory." In fact, the development of "effective sweep width" as a fundamental measure of detection potential was a true stroke of genius on Koopman's part. It was the key that opened search theory's door.]

[JRF – The oft stated notion in land SAR that two low coverage (low POD) searches can produce a higher cumulative POD than a single high coverage (high POD) search when both strategies expend exactly the same total amount of effort in identical segments is shown by Koopman's work to be absolutely false. (This does not prevent, unfortunately, people from arbitrarily picking POD values to "prove" otherwise, at least to themselves. Anyone can "prove" anything if allowed to arbitrarily pick numbers with nothing to back them up.)]

[JRF – Even the concept that POD is related to effort expenditure, another pillar of Koopman's work, seems foreign to land SAR thinking. The idea in land SAR seems to be that POD is related only to searcher spacing, as opposed to searching effort. In fact, this notion has been carried to illogical extremes in some cases. For example, Mr. M. Colwell [9] concluded at one point that because one could send two searchers through a segment at spacing X (larger than the maximum detection range) and get POD Y, and could also send two searchers through at spacing 2X (much larger than the maximum detection range) and still get POD Y, that for some range of spacings the degradation in POD as spacing increased was minimal. It did not dawn on him until much later that ***because the level of effort remained the same (two searchers moving the same distance in both cases), so did the POD*** (which makes perfectly good sense) and that searcher spacing had nothing whatever to do with the POD result. However, at the time he concluded that deploying 5 searchers to a segment (at spacing 2X) would produce the same POD as sending 10 searchers through the segment (at spacing X). This utterly false conclusion was the result of a combination of logical errors called non sequiturs ("it does not follow") and circular reasoning, to wit: A constant POD result from a situation where the effort also remained constant was used to imply that one could, in at least some cases, cut the effort in half with no adverse impact on POD. It is doubtful that anyone involved in either land or maritime SAR would believe that 10 searchers deployed to a segment would do no better in terms of POD than five searchers deployed to the same segment for the same length of time searching at the same speed. Yet Colwell's POD vs. Spacing curves and even his original paper remain in circulation and cited in leading texts and courses in land SAR search management, despite the fact that Colwell himself has withdrawn both the paper and the conclusions reached therein.]

[JRF – In the final analysis, an objective relationship in land SAR between the level of searching effort invested in a segment and the POD such effort can be expected to produce has never been developed. The primary reason for this crucial omission is that the objective measure of detectability developed by Koopman [8], effective sweep width, is completely missing even though it is central to search theory and essential for its practical application. That is also why there is all this debate about whether to "prioritize" segments on the basis of POA, or Pden, etc. when there should be no debate at all—the science of search theory provided the answer about how to optimally allocate the available searching effort well before anyone in either land or maritime SAR even asked the question. The answer involves not just Pden (which contains POA as a factor) but also search speed and most importantly Koopman's measure of detectability—effective sweep width.]

Two of the early pioneers of ISAR, William Syrotuck and Robert Mattson, were field grade officers in the U.S. Air Force, undoubtedly familiar with the SAR techniques developed in the 1940's. Variations from those techniques, and later additions by others (Bownds et al), were not makeshift at all, but rather adaptations to the practical realities of moving from the two-dimensional plane of the ocean to the multi-dimensional land search.
[JRF – Without some specific evidence to the contrary, there is little reason to assume that either Syrotuck or Mattson knew anything about the search theory work of the 1940s or how it was used to develop the maritime SAR methods. I attended the National SAR School in the fall of 1973 when it was still at the USCG installation on Governors Island in New York City. The Officer in Charge at the time was then CDR Frank Meredith, the same person Syrotuck acknowledges in his 1975 paper, *An Introduction to Land Search Probabilities and Calculations* [10]. The USAF officer attached to the National SAR School at the time was none other than then MAJ Robert Mattson. There was no hint at that time in the SAR School curriculum that the maritime SAR procedures being taught had any scientific basis whatsoever. They were taught as "doctrine"—rules without rigorous explanation. It was the operations research folks down the street from the SAR School in the Operations Analysis Branch (OAB) who knew that maritime search planning methods had their roots firmly implanted in the search theory work of Koopman, et al from the 1940s. Almost no one else in the USCG was aware of this information in those days. It seems very unlikely that either Mattson or Syrotuck was any more aware of the details of Koopman's work than typical USCG officers.]

[JRF – As an aside, the description Syrotuck gives of USCG SAR procedures and search planning software in [10] does not correspond with either the U.S. National Search and Rescue Manual (in any of its versions), the curriculum of the U.S. National SAR School then or since, any USCG standard operating procedures, or the search planning software or its accompanying user manuals. Part of the problem may have been that CASP had just been released and was as new to the SAR School staff as it was to everyone else. As a result, CDR Meredith's description of CASP could have left a lot to be desired. Still, it is difficult to explain the significant divergence between Syrotuck's description of maritime SAR methods and the actual documented doctrine and practices.]

[JRF – There was no way for Syrotuck to know, but he should have been corresponding with the Chief of the Operations Analysis Branch on the staff of Commander, Coast Guard Atlantic Area if he was interested in the scientific background of maritime search planning procedures. They were the ones responsible for the USCG's search planning support software. CDR Meredith may not have understood Syrotuck's concerns well enough to refer him to the OAB. At that time I would not have known, either. I stumbled upon the OAB as a source of information only after graduation from SAR School by making a nuisance of myself with technical questions about USCG SAR search planning doctrine and tools while serving as a Rescue Coordination Center (RCC) Controller in San Juan, Puerto Rico, where search planning was an integral part of the job. Yes, I questioned USCG methods then just as thoroughly as I am questioning land methods now. The difference has been that the USCG was able to refer me to the scientific literature where I could get the answers I needed, whereas such cites for land SAR methods simply do not exist. As a consequence of my interest in and study of the scientific underpinnings of USCG search planning methods, I was assigned to the OAB following my RCC tour, where I became the senior system analyst for the USCG's Computer Assisted Search Planning (CASP) system.]

[JRF – Many years later after becoming involved in the study of land SAR, I interviewed Dr. D. Lovelock of the University of Arizona by telephone in 1998. Dr. Lovelock was involved with Dr. J. Bownds, Mr. M. Ebersole, and Mr. D. O'Connor in the development of CASIE. Dr. Lovelock told me that he was unfamiliar with works on formal scientific search theory except for an off-hand comment made by Dr. Bownds one day years before to the effect that, in SAR at least, unlike the wartime efforts Koopman was involved in, searchers usually did not have to worry about being shot at when they found what they were looking for. Dr. Lovelock made some other interesting revelations that will be discussed in due course.]

[JRF – The series of articles entitled "Re-examining the Search Management Function" [11, 12, 13, 14] by Bownds, Ebersole, Lovelock and O'Connor, where the notion of R.O.W. was apparently introduced, does not cite Koopman's work or provide any equivalent discussion. In fact, no references from the scientific literature are cited to support the conclusions and methods given in these articles. The usefulness of cumulative overall POS is downplayed, largely because an incorrect method for computing it is first given and then criticized for being incorrect. The Mattson consensus is criticized and an alternative method is offered that seems to address some of the practical difficulties encountered with Mattson's technique, but in the process introduces equally or more serious difficulties of its own.]

The "controversial topics" of the title are areas where we contend that specific MSAR methods or concepts are either flatly inappropriate for ISAR, or where their use in ISAR should be treated as an option and not a mandate. Because the application of search theory directly affects the deployment of resources and the ability to save lives, criticism and counterarguments will always be carefully considered. We would encourage feedback from all interested parties.
[JRF – Again, it seems clear that basic search theory concepts are being confused with the way they are applied to maritime SAR and are being incorrectly labeled as "maritime

methods." It also appears that "maritime methods" is being used as a catch-all phrase that includes maritime-specific tactics for covering large tracts of open ocean with search effort.]

This white paper is meant to serve a two-fold purpose: first, to reassure practitioners of classic Inland SAR planning that they need not immediately abandon all of its techniques developed over the last 30-odd years, and secondly, to formalize NEWSAR's position on these increasingly controversial topics.
[JRF – Again, this overstates the issue. No one, least of all the proponents of progress with whom this paper disagrees, have ever advocated that land SAR practitioners abandon all their techniques. The issue is much more narrowly focused on just the allocation of the available effort to the searching of areas in those relatively few cases where such searching is required, and how the results of unsuccessful searches are assessed.]

Introduction

Before tackling the areas of controversy, it will be helpful to review commonalities shared by ISAR and MSAR, and some of the differences between them.

The basis of modern search theory can be summed up in the equation:

$$POA \times POD = POS$$

[JRF – Actually, this formula comes from probability theory and is only used by search theory. POS is computed as the joint probability of the search object being in an area and the probability of detecting it if it is there. It is a very serious mistake to think that the above formula sums up the essence of search theory. There is a lot more to search theory than just POA, POD and POS, as anyone who seriously studies the subject quickly learns.]

POA or Probability Of Area, is the likelihood that the subject (target) of a search is in a particular geographic sub-set of the Search Area (SA). In the MSAR world this is called POC, Probability Of Containment. POD or Probability Of Detection, is a measure of a resource's (sensor's) ability to detect the subject if it were actually in the area of interest.

Multiplying POA times POD creates an interaction between locational likelihood and the ability of a resource, or set of resources, to detect objects ranging from small clues, like the stub of a cigarette, to people, downed aircraft and even large vessels. This mathematical interaction creates the value of POS, or Probability Of Success, a measure of how much of the SA was effectively swept, covered or searched.
[JRF – The first sentence of this paragraph reveals another popular misconception—that one can reliably estimate the probability of detecting something, even when it is not known what the "something" is and one has no measure of detectability, not even in concept. A cigarette butt is far less detectable in most circumstances than a person. It borders on both practical and theoretical absurdity to talk of a single POD for finding either a person or a cigarette butt. While one might compute some sort of average POD value for finding one or the other, it would not be a very useful number. If the person is much more detectable than the cigarette butt (as one would normally expect), then the POD for a person will have one value (higher) and the POD for a cigarette butt will have another (much lower) value. Again we see how the lack of any notion or measure of "detectability" severely handicaps the thinking processes for land SAR.]

If a resource with a POD of 80% searches an area with a POA of 40%, then the resulting POS (0.8 x 0.4 = 0.32), assuming all inputs are accurate, is equal to 32%. This means that 32% of the defined SA has been cleared and is not likely to contain the subject. However, the remaining 8% of the starting 40% might still contain the subject. This is due to the fact that there was a 20% chance for the resource, with a POD of 80%, to miss the target.

[JRF – This "cookie cutter" approach is grossly oversimplified, unrealistic and inaccurate. The only way the figures in the first two sentences can be true is if the "definite range law of detection" Koopman described in [8] applies. A definite range law of detection is one where the sensor (searcher) is perfect (100% POD) out to some definite range from the sensor (searcher), and completely ineffective (0% POD) beyond that range. The statements above imply that the POD and Coverage are equal, as with a definite range law of detection up to a coverage of 1.0, and that the area effectively swept is 80% of the segment's total area, leaving 20% completely unsearched. I would also note that the use of the word "cleared" implies such a definite range law of detection. No real-world sensor system behaves in this fashion, certainly not the human eye and brain. In real situations, the use of the word "cleared" should be avoided since it implies near-100% certainty that the object is not present, as in "clearing" a minefield. There is no realistic situation where we could say that 32% of the total search area had been "cleared" due to a 32% POS in one segment. Generally, one goal of searching, and an assumption of search theory, is that within segments, the searching effort is uniformly spread over the segment's area and does not cut out some areas while leaving others untouched. Hence the statement that 32% of the search area (80% of the segment) has been "cleared" is a very serious conceptual error that could easily lead to poor decisions about how resources should be deployed in the next operational period.]

Use of POS in this way assumes that the subject is either stationary or moving in a uniform way, and does not re-enter the searched areas. If the subject is not found and the sum of these POA x POD interactions approaches unity, the incident manager gains confidence, in the case of a maritime search, that the distressed vessel has sunk, or in the case of an inland search, that the subject is not in the SA. OPOS or Overall Probability Of Success, is the sum of all computed POS interactions; it approaches unity when the search has included near exhaustive effort within the defined SA.
[JRF –The above statements about POS, OPOS and their usefulness contradict (fortunately) the position described in Bownds, et al, "Reexamining the Search Management Function, part III" [13], apparently because the correct way to compute cumulative OPOS is now being used.]

Special care must be taken in land searches to ensure that the multi-dimensionality of the SA is considered. Unlike the 2-dimensional surface of the ocean, inland searches, in addition to the normal variations in terrain, can include a myriad of 3-dimensional subareas like lakes, ponds, rivers, trees, tree hollows, hollow logs, caves, wells, graves, mine shafts and buildings, within which are basements, attics, closets, air ducts, chimneys, spaces between walls, crawl spaces, etc., all of which may need consideration as a search segment. With the exception of some specialized searches for high value targets like a lost nuclear submarine, MSAR does not typically search below the surface of the ocean.
[JRF – While the differences described above do exist, they have little to do with the issue of whether search theory is being properly applied. Even in a building, the notion that POD is a function of the amount of effort expended while searching is valid,

although it may be appropriate to come up with a metric for measuring "effort" that is different from "the distance moved while searching" that applies to typical outdoor area searches. Time expended searching in each room might be a better metric for building searches. However, in a building the notion of "clearing" a room is probably valid since a 100% POD is probably possible, unlike the notion of "clearing" a segment in wilderness search where a 100% POD is often virtually impossible. I would also observe that tools like CASIE do not address the "multi-dimensionality" issue any more than CASP or other maritime techniques do. Finally, I would observe that, with the exception of buildings, virtually all land search planning is done on two-dimensional maps and that, for planning purposes, segments are drawn and treated as two-dimensional entities. However, the notion that effort allocation should also depend on variations in search object detectability, probability density, and search speed across the segments is still missing from land SAR.]

As Richard J. Toman has shown, inland bodies of water need to be sub-divided into three segments **[1]**. Buoyancy characteristics of a corpse can vary substantially, placing the recovery subject on the surface, on the bottom of a pond, lake or river, or suspended somewhere in-between.
[JRF – I must respectfully suggest that Mr. Toman check the physics of this problem. It seems very unlikely that a body would maintain neutral buoyancy for any length of time—something that would be required for it to be suspended between the surface and the bottom. So what you really have is a pair of essentially two-dimensional problems—the surface and the bottom. In any case, this still begs the question of whether search theory is being properly applied and whether the available effort is being employed in the most efficient and effective manner. One of the most successful applications of search theory, by the way, has been the hunting of submarines that normally maintain neutral buoyancy for long periods and move in three dimensions between the surface and the bottom.]

Both MSAR and ISAR agree on the mathematical formulation POA x POD = POS. Regarding this formula, Alan R. Washburn notes, "Thus the fundamental Bayesian paradigm is the same in both maritime and inland search. However, the two differ in that the idea of a motion model seems to be missing in inland search; that is, POAs do not 'shift' merely on account of the passage of time." **[2]**
[JRF –It is true that there seems to be no specific motion model in land SAR that accounts for the possibility of search object motion continually shifting the probabilities as time passes. It is also true that implementing any sort of reasonably realistic land motion model in a computer simulation would be extremely difficult since things like terrain, game trails, vegetation, and other features have considerable effects on how lost persons move but are often difficult or impossible to represent with the available information. The rationale in the past seems to have been that lost persons tend to stop moving after some reasonably short period of time, and therefore the solution to the "static" search problem is a reasonable approximation on which to base search plans. CASIE, for example, has no motion model, either.]

[JRF –Most non-statisticians do not understand the Bayesian paradigm. As a result it is often abused and quite false statements are made in its name. What Bayes did was to provide a method for "backwards" reasoning or inference that goes something like this (Hoel, [15]):

> If there are *m* possible mutually exclusive events $e_1, e_2, \ldots e_m$, exactly one of which must occur, and there are *n* possible mutually exclusive outcomes $o_1, o_2, \ldots o_n$, exactly one of which must occur, then given that the j^{th} outcome o_j has occurred, the probability that the i^{th} event e_i was the antecedent of outcome o_j is given by Bayes' Rule:
>
> $$P(e_i \mid o_j) = \frac{P(e_i) \times P(o_j \mid e_i)}{\sum_{k=1}^{m} \left[P(e_k) \times P(o_j \mid e_k) \right]}.$$

That is, if we know the unconditional probabilities for the occurrence of each event $\boldsymbol{e_i}$, and we know the conditional probabilities for each outcome $\boldsymbol{o_j}$ to occur if event $\boldsymbol{e_i}$ occurs, we can compute from an observed outcome $\boldsymbol{o_j}$ the probability that it was preceded by event $\boldsymbol{e_i}$.]

[JRF – Example: A family had plans to go fishing on a Sunday afternoon, but their plans were dependent on the weather at noon Sunday. If it was sunny, then there was a 90% chance that they would go fishing. If it was cloudy but not raining, then the probability that they would go fishing would drop to 50%. And if it was raining, the chances dropped to 15%. The weather prediction, which we can assume to be accurate, called for a 10% chance of rain, a 25% chance of clouds, and a 65% chance of sunshine.

Set possible antecedent (prior) events and their unconditional probabilities

S as the event that the weather is sunny at Sunday noon
C as the event that the weather is cloudy at Sunday noon
R as the event that the weather is rainy at Sunday noon
P(S) = 0.65, P(C) = 0.25, P(R) = 0.10

Note that P(S) + P(C) + P(R) = 1, and of course S, C and R are mutually exclusive events.

Set possible outcomes and compute their probabilities

F as the outcome that the family goes fishing
N as the outcome that the family does not go fishing

P(F|S) = 0.90, P(F|C) = 0.50, P(F|R) = 0.15

P(F) = P(F|S) P(S) + P(F|C) P(C) + P(F|R) P(R)
= (0.90)(0.65) + (0.50)(0.25) + (0.15)(0.10)
= 0.585 + 0.125 + 0.015
= 0.725, or about 72.5% probability that the family would go fishing.

P(N|S) = 1.0 – 0.9 = 0.10, P(N|C) = 0.50, P(N|R) = 0.85
P(N) = P(N|S) P(S) + P(N|C) P(C) + P(N|R) P(R)
= (0.10)(0.65) + (0.50)(0.25) + (0.85)(0.10)
= 0.065 + 0.125 + 0.085
= 0.275, or about 27.5% probability that the family would not go fishing.

Note that P(F) + P(N) = 72.5% + 27.5% = 100%, indicating that all possible outcomes have been accounted for.

Evaluate the antecedent event probabilities based on each of the two possible outcomes.

1. The family is observed fishing Sunday afternoon. What can we infer about the weather at noon that Sunday?

P(S|F) = probability weather was sunny at noon, given that the family went fishing.
= P(F|S)*P(S)/P(F)
= 0.90*0.65/0.725
= 0.807, or about an 81% probability that the weather at noon was sunny.

P(S|F) = probability of cloudy weather, given that the family went fishing.
= P(F|C)*P(C)/P(F)
= 0.50*0.25/0.725
= 0.172, or about a 17% probability that the weather at noon was cloudy.

P(S|F) = probability of rainy weather, given that the family went fishing.
= P(F|R)*P(R)/P(F)
= 0.15*0.10/0.725
= 0.021, or about a 2% chance that the weather at noon was rainy.

Note that P(S|F) + P(C|F) + P(R|F) = 0.807 + 0.172 + 0.021 = 1.000

2. The family is observed shopping at the mall Sunday afternoon, i.e., not fishing. What can we now infer about the weather at noon that Sunday?

P(S|N) = probability weather was sunny at noon, given that the family did not go fishing.
= P(N|S)*P(S)/P(N)
= 0.10*0.65/0.275
= 0.2364, or about a 23.6% probability that the weather at noon was sunny.

P(S|N) = probability of cloudy weather, given that the family did not go fishing.
= P(F|N)*P(C)/P(N)
= 0.50*0.25/0.275
= 0.4545, or about a 45.5% probability that the weather at noon was cloudy.

P(S|N) = probability of rainy weather, given that the family did not go fishing.
= P(N|R)*P(R)/P(N)
= 0.85*0.10/0.275
= 0.3091, or about a 30.9% chance that the weather at noon was rainy.

Note that P(S|F) + P(C|F) + P(R|F) = 0.236 + 0.455 + 0.309 = 1.000

Putting this into SAR terms, the outcome and events corresponding to unsuccessful search are: subject was not found, subject was in segment 1, subject was in segment 2, … subject was in segment ***n***. The unconditional probabilities are the POAs for each of the segments. The conditional probabilities are: probability of detecting the subject given he/she was in segment 1 (i.e., $P(D|S_1)$ = POD for segment 1), POD for segment 2, … POD for segment ***n***. The question a Bayesian POA update really answers is, "Given an unsuccessful search of a segment, what can we infer about the relative probability that the search failed because subject was in that segment but not detected during the search vs. the probability that the search failed because the subject was not in the searched segment but elsewhere?" For each of the unsearched segments, we can also ask and answer the question, "What is the relative probability that the search failed because the subject was in this (unsearched) segment vs. the probability that the subject was in the searched segment but was not detected?" It is also possible, of course, to do Bayesian updates on multiple segments and get a final result all at once to ease the computational burden, but the principle remains the same. All other things being equal (same size segments, same detectability, same search speed, etc.), in the next operational period we will want to search those segments where the subject's presence was the most likely "cause" for previous searching to fail. Note that when viewed this way, it does not matter whether a segment has been previously searched or not. Usually searched segments will have lower probabilities of having "caused" the search to fail by virtue of the subject's presence in them, but such a result is not guaranteed.]

For ISAR, initial POA is generally established by a set of best guesses from a panel of experts. For MSAR, initial POA is developed through mathematical models driven by known or forecast environmental conditions like winds and currents. POD is a highly calibrated number in MSAR with its cadre of professional searchers. In ISAR, POD is more problematic and often simply an informed estimate. The lack of highly calibrated sensors in ISAR is not by choice but rather the nature of the beast. Calibration of sensor coverage and derivative POD requires time, money and a unifying command authority not presently available to the ISAR community.
[JRF – This description of "MSAR" is incorrect. Initial POA is ***not*** a function of the environment except to the extent that the environment (e.g., fronts and storms) might

have been the cause of the distress. The closest analogy to the lost person on land is the overdue vessel at sea. The initial POA distribution is established by a set of "best guesses" (called "scenarios") about the likely behavior of the vessel's operator given whatever information can be obtained about his/her intentions (plans) and how he/she would likely react to various circumstances that might have arisen since departure (casualty aboard the craft, encounter with heavy weather, etc.). The probabilities of casualties and encounters with hazardous conditions are also assessed. Certain standard statistical models are used to represent uncertainties about the craft's actual location around reported or intended positions (last reported positions, intended turn points, etc.), along intended tracks, and in intended operating areas (e.g., fishing grounds), rather than lay down a grid of cells and assign POA values by hand. However, the possible base positions, tracks, and areas are determined subjectively using information gathered from reporting sources familiar with the craft and operator and evaluated in a manner similar to a land SAR "consensus." The statistical models produce probability density distributions that are then mapped to a regular grid for display purposes. Different scenarios can also have different subjectively determined weights to represent different likelihoods of being the "true" scenario that describes what actually did happen to the craft.]

As Washburn perceptively notes, ISAR and MSAR differ in other fundamental ways: "The inland SAR situation is essentially different from the marine situation in that many more organizations are involved. . . . inland SAR is conducted by a host of organizations, most of them voluntary. . . . The diffuse nature of the responsibility for inland search leaves it without a sponsor for development of either theory or software." The differences are not just organizational, as Washburn continues, "Inland search must cope with the effects of terrain, a complication that is missing in maritime search." **[3]**

[JRF – In this last instance, Washburn went on to just as perceptively note that:

> Whatever the explanation for the current lack of sophistication in inland search theory and TDAs [tactical decision aids], and whatever the organizational difficulties of achieving a remedy, it is probably true that better TDAs in the hands of well trained inland search managers would find more targets. There is evidence of such improvements for both the Navy and the Coast Guard in the maritime case. Inland search, with a larger incident base and additional complicating features such as the effects of terrain, should be an even better candidate for improvement (p. 7-10).

We would add one other salient difference: the potential for foul play. Outside of combat situations, the underlying assumptions for finding a missing vessel in MSAR are driven by measurable physical factors like wind and sea currents. While maximum theoretical distances can be computed for ISAR searches, statistical distributions of lost person behavior are rudimentary where they exist at all. In ISAR, initial and subsequent assumptions are not confined to physical limits but are subject to the vagaries of the human psyche. Human agents can and do fake their own disappearance, and the subjects themselves vary broadly: hunters, hikers, elderly Alzheimer victims, children, generic "missing persons," etc., all of which exhibit behavioral differences across classes and as individuals within broad classes. Some incidents are searches for abductees or other victims of foul play. Because of the highly volatile human elements, every ISAR Search Area, unlike MSAR target spaces, must always be treated as a potential crime scene. [JRF – Actually, the statistical distributions for lost person behavior seem to have improved quite a bit and should be quite useful. While wind and current are measurable quantities, there is generally very little observation going on at the scene of a distress at sea until search units arrive on scene, and even then only limited observations are possible.]

[JRF – I fail to see why humans aboard vessels and aircraft are any less subject to the vagaries of the human psyche than humans on land. There are just as many classes (commercial fishermen (with several sub-classes depending on geography, type of fishing, etc.), yachtsmen (with sub-classes of at least sailing and power boats), John Q. Public out in his small boat (many sub-classes depending on activity), and just as much individual variation as on land. Furthermore, once out of sight of land, a disoriented boater may go in any direction with equal ease, especially if there is no navigation equipment aboard and it is overcast so not even a reference to sun or stars is available to tell north from south, east from west.]

[JRF – An area of ocean sometimes does become a "crime scene", as when a smuggler throws bales of marijuana overboard which must then be recovered as evidence, but I do agree that the "crime scene" issue is much more important on land than on the water. Evidence at sea tends to sink or drift away whereas on land it may remain in place for months (as in the Chandra Levy incident) or even years.]

ISAR has also developed the concept of the "Rest Of the World" (ROW), missing in the closed systems of MSAR. ROW acts as a shadow segment in ISAR, accumulating POA as segments are swept and the missing subject is not found. ROW is a characteristic of an open system, one that allows the possibility that the subject is not in the defined search area. ROW represents the space, i.e., the remainder of the planet, outside of the Search Area.
[JRF – I agree with Dr. C. Twardy that the R.O.W. issue is a red herring. In my interview with Dr. Lovelock, he admitted that at the time CASIE was initially developed, the developers did not understand POS very well. R.O.W. was "invented" to take its place. One apparent (but not real) problem with so-called "closed" systems is that when POA values are updated and re-normalized in Bayesian fashion, the total of all POA values comes out to 100% every time. Unless one knows how to compute and track cumulative overall POS, there is nothing to indicate when continued searching there no longer has an appreciable chance of success. The cycle of search, update POAs, search, update POAs, … becomes an infinite loop, which is acceptable only if the search planner is absolutely certain there is something to be found in the search area and the sensors in

use will detect it eventually. However, if un-normalized updated POA values are tracked, they will gradually fade away to zero, indicating there is nothing there that the available sensors can detect. Similarly, the cumulative overall POS will approach 100% more and more closely, indicating exactly the same situation. Tracking un-normalized POA and cumulative overall POS values both give clear indications of when the available information on which the initial POA values were based has been exhausted. At that point, either search operations should be suspended or new scenarios should be developed by re-examining all the available data.]

[JRF – Since POS was not properly understood initially, it was necessary to develop something to take its place—R.O.W. R.O.W. acts like a one-way "relief valve" through which probability is "bled off" from the search area to a phantom segment using the "pump" of re-normalization that returns the sum of all POA values to 100%. However, R.O.W. POA does not have any quantitative usefulness. An overall POS of 90% (whether from a "closed" or "open" system) indicates that no matter how much additional searching and investigative effort is thrown at the problem on the basis of the current planning parameters, future chances will be no better than one in ten for locating the subject. An R.O.W. POA of X% is meaningless. For example, if the initial R.O.W. POA is 5% and the overall POA for the search area is 95%, then an overall cumulative POS of 90% (nominal cumulative POD of 94.7% across the search area) will produce a re-normalized distribution where the overall search area POA is 50% and R.O.W. POA is also 50%. What does this actually mean? One reason the search could have failed was because object was in the search area, but searchers failed to detect it. The other reason is that the search object was not in the search area. In the above example, these two possibilities are equally likely. How does this aid the search planner? Note that when the initial R.O.W. POA is 10%, the same 50-50 result is produced with an overall cumulative POS of only 80% (nominal cumulative POD of 88.9% across the search area). If the initial R.O.W. POA were 20%, as some researchers in Alberta have recommended, then an overall cumulative POS of only 60% (nominal cumulative POD of 75% across the search area) would produce a 50-50 split between the search's failure being due to missing the subject in the search area, vs. the subject not being in the search area at all.]

[JRF – In 1998, Dr. Lovelock could not recall whether they had ever figured out how to handle POS correctly. When I refreshed his memory about how the code in "Bigplan.C" worked (using cumulative overall OPOS, even though it was called simply "sum"), he agreed that they must have figured it out after all.]

In MSAR, there is typically no ROW. The probabilities associated with swept areas recycle through the SA, with total POA equal to the sum of the initial POA after an infinite number of updates. MSAR techniques generally assume that the SA, as defined, always contains the missing subject within the closed system.
[JRF – To someone unfamiliar with maritime SAR operations, this may appear to be the case. However, the R.O.W. issue is handled in maritime SAR by developing alternative scenarios to explain behavior that would put the missing craft or its occupants in some

situation other than distressed and adrift on the ocean. An interesting fact, so far overlooked, is that with or without R.O.W., the optimal allocation of searching effort to the search area is exactly the same. This is another reason R.O.W. is essentially useless. Optimal effort allocation methods, including the one in CASIE, use cumulative overall POS as the "figure of merit" or "measure of effectiveness." R.O.W. POA is not used for this purpose. While it is technically true that maximizing cumulative overall POS also maximizes R.O.W. POA (after re-normalization), these values answer two quite different questions. Cumulative overall POS for either a "closed" or an "open" system answers the question, "What are the chances that all the searching done to date would have located the search object if all the information used to plan the searches, including POD estimates used to update POA values, were correct?" On the other hand, R.O.W. POA tries to answer the question, "What are the relative chances that the searching to date has failed because the subject is not in the search area, assuming all the information used to plan the searches, including the POD estimates used to update POA values, were correct?" The reason we say "tries" is that no allowance is made for the very real probability that the subject will be located somewhere outside the search area by non-searchers (e.g., investigators or just passers-by). This is a serious omission because a true Bayesian update requires covering all the possibilities. Cumulative overall POS, on the other hand, is well defined in that it measures only the probability that the ***searching*** effort done to date would have found the subject if all the search planning parameters were correct.]

[JRF – The omission just cited leads to an important statistical flaw in the way the R.O.W. concept is employed in land SAR: It is incomplete. Note the requirement in the earlier statement of Bayes' Rule (from Hoel, [15]) to consider all possible outcomes. Although in actual practice subjects are found with a non-trivial frequency outside the search area and not in distress, the so-called "open" system does not account for this possibility. It assumes that the subject will never be found outside the search area by investigative or other non-search means. (This immediately begs the question, "If it is assumed there is no possibility of finding the subject in R.O.W., how is that different from assuming that the only place to find the subject is in the search area, as in a 'closed' system?") The reason for the omission is simple. If one acknowledges the possibility of finding the subject outside the search area, then one must also acknowledge some probability that such a find will occur—i.e., a "POD" for R.O.W. Since no techniques for assessing such probabilities have ever been developed, it is ignored. Yet the Rule of Bayes cannot be properly applied without it. In short, Bayes' Rule can only be applied to so-called "closed" systems that account for all of the possible events and outcomes and their respective probabilities. The way it is being applied to so-called "open" systems is merely a sleight of the statistical hand to get around a perceived problem that never should have arisen in the first place.]

Proponents of MSAR techniques for ISAR insist that ROW be dropped in favor of a closed system, the subject of Topic 1. This unyielding attitude is curious, since the field of Operations Research (OR) makes no such demand. In OR, a probability distribution which does not sum to 100% is called a "defective" one. Except for special cases,

defective target distributions are usually allowed. When a distribution sums to less than 1, "this simply means that the target has some probability of being outside the region in which (the) search is to be conducted." **[4]** In ISAR, we call that area outside the region where the search is conducted the Rest of the World.
[JRF – Again, there are ***NO*** "proponents of MSAR for ISAR." Such statements indicate either a complete misunderstanding of what the proponents of change are proposing, or a deliberate attempt to misrepresent the issues and create a confrontation. There is likewise nothing in the proposed changes that prevents use of a defective distribution. All the concepts, methods, formulas, and equations will work just fine. However, when the objective is to develop an optimal search plan, there is nothing wrong with assuming that all of the probability relevant to searching (as opposed to other activities) is in the search area. Such an assumption also makes conceptualization and computation much easier, with no loss in accuracy or validity when it comes to deciding where to place search resources.]

[JRF – I am not aware that anyone is "insisting" that R.O.W. be dropped. We have merely pointed out that it is not very useful for planning the search effort, which is necessarily dedicated to the assumption that the subject is in the search area. To use R.O.W. at all for search planning requires vast amounts of computation that can be avoided while still achieving the desired results. When the POA update problem was first put to me, it was couched in the following terms: "We know we should do POA updates but they require so much computation that no one does them, or if they do, they are prone to error due to the number of computations required." Knowing how the USCG's CASP system addressed the POA update problem, I simply recommended following the same computational procedure. (This is all math, by the way, and has nothing to do with land vs. maritime search.) That procedure calls for updating POA values with the simple formula,

$$POA_{NEW} = (1\text{-}POD)*POA_{OLD}.$$

If this scheme is repeated as more and more searching is done in each segment, the successive POA_{NEW} values will approach zero, and R.O.W. POA will never change. Re-normalization, if one wishes to insist on all the POA values adding to 100% as in a "closed" system, is a simple matter of adding all the current POA_{NEW} values plus the unchanged R.O.W. POA to get a total probability remaining, and then dividing each individual POA_{NEW} value by that sum, including the R.O.W. POA. However, it is the un-normalized values, which are much easier to compute, that need to be tracked.]

[JRF – Note how using R.O.W. is called an "open" system, but in order to work, it forces the primary characteristic of a so-called "closed" system—namely the sum of the POA values must always equal 100%. Un-normalized POA values and cumulative overall POS values impose no such restriction. In fact, as soon as some searching is done in a so-called "closed" system, it becomes "open" since the sum of the un-normalized POA values in the search area is no longer 100%. However, it is a natural consequence of the mathematics that the sum of the un-normalized POA values and the cumulative overall POS will always equal the sum of the initial POA values, but that initial sum does not have to be 100%. So, what is "closed" and what is "open?"]

[JRF – In the end, all I did was show a simpler, faster, easier, and far more efficient way to do the computations for POA updates. In the process, this showed that R.O.W. POA was useless for search planning purposes if the standard criterion of maximizing the cumulative overall POS in the minimum time was used. As stated previously, not even CASIE III uses R.O.W. POA to evaluate the different possible combinations of segments and resources to determine which is the best allocation. It uses cumulative overall POS as the optimization criterion, and then computes and displays R.O.W. POA afterwards. It should be an extremely simple matter to have CASIE III (and presumably any subsequent versions) display the cumulative overall POS it computes and uses either instead of or in addition to the R.O.W. POA.]

[JRF – On the issue of CASIE, a shortcoming that is difficult to overlook is its dependence on subjective POD values that do not consistently relate POD to the amount of searching effort the associated resource represents for the given segment. In short, CASIE is forced to allocate effort without any input on the relationship between the level of effort expended in a segment and the POD that can be expected. No program can produce valid outputs from invalid inputs.]

Topic 1: Open Systems vs. Closed Systems

In our view, the second-most misplaced idea from proponents of MSAR techniques is the insistence that ISAR operations be confined within closed systems. Certainly, successful searches can be conducted inland with closed search areas. However, a closed area severely limits a number of adaptive qualities characteristic of open systems.
[JRF – There is no difference between "open" and "closed" systems. A system that uses R.O.W. is just as "closed" as a system that does not—in fact, it is more so since a system that uses R.O.W. ***requires*** the sum of all updated re-normalized POAs to always be 100%. I suspect the assertion that "open" and "closed" are different stems from a limited understanding of POS and how to use it.]

Among the advantages of an open system are the following:

1. The ability to start a Search with a few segments, without having to divide up the entire theoretical Search Area, easing the initial computational burdens and mapping tasks by eliminating areas that are not immediately relevant.
   [JRF – This has nothing to do with "open" or "closed" and no one has ever argued, so far as I am aware, that you cannot start with a few segments and even assign POA values that do not add to 100% if you like. If the POAs in the few segments sum to, say 60% initially, then either the remaining 40% is all in the remainder of the "theoretical" search area (which you would call a "closed" system) or some of it is there and the rest is in the phantom R.O.W. "segment" (i.e., an "open" system).]

2. The ability to "follow the clues," i.e., to expand the Search toward the subject by adding additional segments based on new information without the requirement of developing a new consensus.
   [JRF – I really do not understand this statement, and other similar statements made elsewhere in this document. It sounds like you are saying that when clues or other significant information comes to light after the initial consensus, you do not re-evaluate the situation in light of this new data. I thought the whole reason for a consensus was to evaluate all the available data. If more data becomes available or the initial data is revised, how can you reasonably avoid a new consensus unless the new evidence completely overwhelms all previous data? One of the huge advantages of tracking un-normalized POA updates as recommended above is the ability to take a new set of initial POA values from a new consensus and apply all searching done to date to that new set in one easy step to get new updated POA values for the current point in time. It has been my understanding that the chief objection to doing a new consensus was the unnecessary computational burden previously imposed because the un-normalized POA values were not tracked. The proper combination of POA values from a new consensus and the relevant cumulative POD values (all searching done to date) makes the application of a new consensus both easy and useful. In fact, CASIE III already computes cumulative OPOS values from the initial consensus POAs by applying the cumulative PODs. A change to the software to allow it to keep the

cumulative POD values from all searching done to date handy while allowing any new set of "initial" POA values to be input would give it this capability if it is not already present. In any event, "following the clues" is not an "open" vs. "closed" issue.]

3. Allow the inclusion of non-contiguous segments. Did the despondent subject travel to a summer home out of the primary search area?
   [JRF – Again, this has nothing to do with "open" or "closed" systems. Non-contiguous segments can and do occur in both maritime and land SAR. No one is arguing with that. What you have described is an alternative scenario, that's all.]

4. Monitor R.O.W. probability, the likelihood that the subject is no longer in the Search Area, or in the case of Bastard Searches, never was.
   [JRF – As described above, the R.O.W. POA only tries to answer the question, "What is the probability that the search failed because the subject was not in the search area?" However, as also shown above, the value of updated R.O.W. POA is extremely sensitive to the initial value assigned, so one cannot simply say, "When R.O.W. POA reaches X%, it is time to suspend search activities." One should be very careful about making such a statement, even with cumulative overall POS, but at least a cumulative overall POS equal to 90% of the initial overall POA in the search area always means the same thing about maximum chances that future searching there will be successful (10% of the initial overall POA in the search area, to be exact).]

5. Deal with new information just outside the defined Search Area by expanding the SA out of R.O.W. and adding the Influence of Clue to shift POA toward the newly created segment.
   [JRF – Again, I do not understand how anyone can deal with new information correctly if they do not re-evaluate the entire data set with the new information included. This also begs the question, "What exactly does R.O.W represent?" If it represents, in whole or in part, the likelihood that the subject is not only not in the currently defined search area but may not even be in distress, having gone somewhere else entirely, then you cannot justify just taking some of the R.O.W. POA and applying it to the new segments obtained by expansion. Only if R.O.W. is part of the same scenario and really part of the "possibility area" (which brings us back to a "closed" system in the end) can you justify assigning R.O.W. POA to the new segments. Trying to cover multiple mutually exclusive scenarios (e.g., "the subject is lost in some general area and in need of assistance but his exact location within that area is unknown," vs. "the subject is not in the general area and probably not in need of assistance, or at least not the sort that SAR personnel can provide"), with a so-called "open" system and one "shared" R.O.W. POA shows muddled thinking. These are two completely separate scenarios that cannot both be true. It is either one or the other and trying to combine them through a single shared R.O.W. POA is conceptually, statistically and logically unsound.]

[JRF – There is insufficient room for a complete explanation here, but consider the following: There are two mutually exclusive scenarios. In Secnario S1, the subject is lost and in need of assistance in some general area, but his exact location is unknown. In Secnario S2, the subject is not lost, not in the search area, and not in need of SAR assistance. The general area cited in S1 should be divided into probability regions based on general lost person behavior statistics, specifics of the terrain, specific information about the particular subject involved, etc. This constitutes a so-called "closed" system based on the assumption that S1 is true. The entire "theoretical" search area should be broken in to probability regions with subjective POAs assigned through an analysis and consensus process, but these regions can be quite large and therefore few in number since "searchability" requirements need not be considered at this point. Based on the consensus results, it may be possible for the search planner to make some intuitive judgments about where to search initially and segment just those regions for search resource assignment purposes. Mathematical algorithms also exist that can actually compute an optimal allocation of effort. Meanwhile, scenario S2 (call it R.O.W. if you like) is addressed through investigative techniques. Since any conflict or overlap of resources available to do searching vs. investigating seems unlikely, these are in fact two separable problems and should be treated as such.]

[JRF – The correct way to deal with the two separate issues that R.O.W. tries to address is as follows: If new information comes to light that affects S1 (clues found by searchers, additional information about the subject or his plans, etc.) then a new consensus is required to properly evaluate this information, add, expand or delete probability regions as appropriate based on the new consensus, and revise initial regional POA values (all of the preceding will cause revisions in the segment POA values as well). Then it is necessary compute new current POA values based on the revised initial POA values in order to account for searching already done (this is not computationally difficult). Next, proceed to optimally allocate the available resources for the next operational period using appropriate techniques that are based on good science (which can require a computer). The relationship between S1 and S2 can be handled with scenario "weights." If one were to assign a weight of "9" to S1 and a weight of "1" to S2, this would be interpreted as S1 being 9 times as likely to be true as S2. After some searching, it is still possible to answer the question, "What is the relative probability that searching to date has failed because the subject was not detected despite being lost and in need of SAR assistance vs. the probability that the subject was not in the general area and not in need of SAR assistance" by applying the scenario weights in a statistically appropriate fashion.]

[JRF – It is extremely important to realize that searching and investigating do not affect the original probabilities of whether S1 or S2 is true. They only affect our assessment of why the subject has not yet been found.]

6. Provides the potential to Shift POA without POD. POA is not recycled internally, but can be reintroduced into the defined Search Area from the accumulated total in ROW.

The search effort of resources that usually do not produce POD, like tracking dogs, hasty teams, man-trackers, etc. can be quantified as clues and used to shift POA. [JRF – Please provide academically/scientifically recognized cites to support this position. The notion of building up POA in R.O.W. through the re-normalization process after each operational period, and then subjectively re-distributing it back into the search area for any reason does not seem either statistically or logically valid. In addition to comments above about when it is and is not valid to "shift" POA between R.O.W. and the search area, it is very dangerous to do "shifts" on the basis of negative search results without an associated POD. The reason it is dangerous is that you are tacitly assuming a POD of 100% for those "resources that usually do not produce POD." On the other hand, if there are positive results, like discovery of a clue, then such results should be treated as any other evidence or information about the situation should be treated—through the consensus process.]

The list is not meant to be comprehensive, but representative of useful adaptations when employing open systems. Table 1 summarizes some of the differences between open systems in ISAR and closed systems in MSAR. The abbreviation "TDA" under TDA Support refers to Tactical Decision Aids, or computer programs used to manage the Bayesian mathematics and other associated search tasks, discussed in more detail as the fourth topic.
[JRF – Table 1 is almost entirely incorrect, and shows a nearly complete misunderstanding about maritime SAR procedures, the IAMSAR Manual, the U.S. National SAR Supplement, and the USCG Addendum to the National SAR Supplement. Further comments follow the table.]

Closed systems require the SAR planner to define a search area that guarantees containment of the subject (target). This makes sense in MSAR where lack of a find indicates a vessel has sunk. In ISAR, this causes the Search Area to be over-defined, much larger that it need be if ROW was used. With ROW, the ISAR planner can grow the search toward the subject, on the basis of clues, as new information arises.
[JRF – Again, this is an attempt to combine that which cannot be logically combined—two mutually exclusive scenarios—one of which assumes the subject is lost and in need of assistance somewhere in a general area and another that assumes some other situation is true. R.O.W. cannot be used to reduce the size of the "possibility area" where the subject could be. The decision about the best way to deploy the available search effort can be made through scientifically validated methods that will allocate the available effort in ways that are most likely to produce positive results. Very often such allocations will not cover the entire "possibility area." But just defining a few segments for searching and lumping the rest of the probability into R.O.W. is most definitely ***NOT*** the way to go about solving the effort allocation problem.]

Table 1. Characteristics of ISAR Open & MSAR Closed Searches

	Characteristic	Open-Inland	Closed-Maritime
1	Search Area is 3-Dimensional	Yes, but it doesn't matter	Yes, but it doesn't matter
2	Includes R.O.W.	Yes, but it doesn't matter	Handled as one or more scenarios, but it doesn't matter
3	All Segments must be pre-defined	Yes or No	Yes or No
4	Initial POA Distribution must encompass entire SA (No R.O.W.)	No	No
5	Initial POA Distribution derived from Physical Properties of Target and Environment	Always a factor	Always a factor
6	Initial POA Distribution from Behavioral Properties of Humans	Always a factor	Always a factor
7	Conducive to the discovery and assessment of Clues	Yes	Yes
8	POA changes over time, even if no search	It should if the subject is moving or if new information, clues, etc. come to light.	Yes
9	Can accommodate noncontiguous segments	Yes	Yes, and it happens frequently.
10	Can be readily applied in criminal investigations	Yes	Yes. Drug and migrant interdiction surveillance patrols
11	TDA Support	CASIE3 (DOS) – Free CASIE4 (WIN) – Free	CASP (USCG) NODESTAR (USN) both proprietary

[JRF – A recurring theme in the original discussion is that it regularly appears to be trying to avoid perceived procedural or computational problems by taking imaginative but uninformed shortcuts of various kinds. The proponents of change have better and easier ways to address the same issues that do not require shortcuts. This is another advantage of the scientific approach—it is often actually simpler that what a non-scientific approach might produce.]

[JRF – 1. The ocean's surface under typical conditions involving SAR cases is quite 3-dimensional. Not only that, it moves—which the ground does not. Searching from a vessel is no picnic in 30-40 foot seas and 30-40 knot winds. Someone once said that a man who goes to sea for fun would go to hell as a pastime. Waves and spray can obscure search objects just as surely as ridges and vegetation. Vessel movement in rough seas is slower and fatiguing to the crew just as negotiating rough terrain is on land. Even air crews are adversely affected by rough weather and turbulence at the low altitudes they typically fly. In any case, both maritime and land search planning is done on two-dimensional charts/maps and so, for this discussion, the dimensionality issue is largely moot.]

[JRF – 2. Inclusion or exclusion of R.O.W. will not affect the proposed effort allocations for optimal searches that maximize cumulative overall POS in the minimum time. This is a red herring and is irrelevant. Unlike land search areas, maritime search areas both move and expand constantly, and there is no need to explicitly deal with R.O.W. for area expansion purposes. Maritime search areas just expand as needed, with consequent appropriate re-evaluation of POA values. So in some sense, maritime methods deal with regions outside the current search area (one part of R.O.W.) better and more naturally than land methods, even though R.O.W. is never specifically mentioned. Also, maritime methods handle alternative scenarios well (the other part of R.O.W.), both those that might require searching areas and those that require only investigation, such as port checks to see whether the operator changed his plans without telling anyone and showed up somewhere unexpected safe and sound.]

[JRF – 3. This is probably a semantic issue, at least partially. The term "segment" is not used in maritime SAR, so it is difficult to know what element of maritime SAR it refers to in this context. In maritime SAR, the search planner develops scenarios about what the operator/craft did. Each scenario defines a probability density distribution on where and when the distress might have occurred. These distributions are represented by combining standard statistical distributions known to represent the kinds of uncertainty found in the input data (reported/estimated positions, intended tracks, planned operating areas, etc.). The distributions are displayed by laying down a regular grid, computing the POA for each grid cell, color-coding the results and also showing the POA values in percent. However, cells are not segments because maritime search sub-areas are generally quite large and each includes many cells of the probability map. In both maritime and land search, the area assigned to a particular resource must be defined in advance of sending the resource there. In maritime SAR, the cells of a probability map are not pre-defined. In fact, the cell size is a selectable item each time a probability map display is computed. The same distribution can be "mapped" several times using a different cell size each time. CASP distributions are updated for both search object drift and the effects of unsuccessful searching as time passes. Since the effects of drift can be only roughly approximated, the uncertainty in search object position grows with the passage of time, which makes the probability distribution become larger and more diffuse.]

[JRF – 4. In maritime SAR, there is no requirement that the entire distribution be defined in the sense intended here (no R.O.W.). In fact the CASP software can quite literally include the rest of the world and assign it a POA value. However, this is not at all useful and is never done. It is a natural consequence, not a requirement, of the way probability density distributions are generated that they usually define the entire possibility area for the associated scenario. It is still possible for the search object to be outside of the generated probability density distribution, although this is rare. R.O.W., in the sense of not being in distress but in some other non-SAR situation despite being reported missing, unreported or overdue, is handled via alternative scenarios that are then checked out by various investigative means.]

[JRF – 5. & 6. In both land and maritime SAR, these factors must all play a role in every case. The physical environment and the nature of the subject/search object must always affect where the subject/search object may be at the time a search effort is mounted. As previously described, behavioral factors are equally important in both land and maritime SAR. The only real difference is that maritime SAR has no specific studies of "lost mariner behavior" to draw upon. This would be an interesting topic to study, but it is far from obvious whether any useful trends or groupings could be found in the maritime case. At present, each case is treated individually, with a lot of effort expended in interviews with various reporting sources (all that can be found) who know the missing operator's plans, habits, tendencies, attitude, capabilities, etc., along with information on the navigational equipment carried, maintenance issues, alterations to the craft, survival equipment carried, and on and on. It is the behavioral picture that emerges from these extensive interviews that defines the various scenarios used to create the initial probability distributions. To state that behavioral properties of humans are never considered in maritime search planning is simply and totally inaccurate.]

[JRF – 7. Based on limited anecdotal evidence, it appears that maritime searches turn up debris (clues) from a SAR incident about as often as land SAR turns up clues left by the subject. A debris find is always taken seriously and thoroughly evaluated. Unlike land search, however, there is no guarantee that the debris will drift in the same direction as the search object (e.g., a life raft). Wind is often the primary driving force for drift, and the leeway characteristics of debris and search objects of interest where survivors may be located are often significantly different. This means the debris drifts in one direction while the survivors drift in another. Unfortunately, a debris find on the ocean does not establish a direction of travel. Assessment of debris usually takes the form of trying to estimate where and when it could have come from as a way of estimating the time and location of the distress incident itself. When these can be reasonably estimated, then a new scenario based on that information is created and put into the search planning hopper. In addition, drifting objects leave no tracks or other evidence of passage in the ocean, and debris is not continuously ejected to leave a trail leading to the search object. Hence it is not possible to transform the search problem into a tracking problem in the maritime case.]

[JRF – 8. Land POA values certainly should be modified as time passes to account for new information and to account for subject movement in situations where it is believed that the subject is still moving in some fashion. It is both statistically and logically incorrect to believe that only "R.O.W." and new segment POAs are affected by the arrival of new information. This is a shortcut that is both invalid and unnecessary.]

Topic 2: Grid Searching and Manpower Requirements

[JRF – This entire section is devoted to belaboring the obvious—very large areas cannot be practically searched with small to moderate numbers of people unless aerial search can be effectively employed. I am not aware of any dispute on this point and wonder why it is discussed at such great length.]

A closed search area generally indicates grid searching as the primary detection tool. In ISAR, a grid search is often considered a last resort, a manpower intensive technique destructive of clues. Since the maritime environment is not clue rich (no footprints left in the water), and distances are vast, grid searching for the subject (lost person or vessel) via aircraft is the primary technique in MSAR.
[JRF – A so-called "closed" search area and grid searching have nothing to do with each other. The effort allocation, POD estimation, and search evaluation techniques the proponents of change advocate work equally well for all search tactics where the coverage of areas is involved. This includes, for example, small teams using "purposeful wandering." The notion that we are entrenched in a grid search technique using closely spaced searchers moving in parallel stems from a holdover of old prejudices unique to the land SAR community and a lack of understanding of the recommended new methods. It also stems from an assumption that because maritime SAR generally employs parallel sweep search patterns, the proponents of change (only one of whom is a mariner) advocate that technique as the only worthwhile technique. This assumption is absolutely false.]

The following example is offered to demonstrate the feasibility of grid searching in Maritime searches and its inappropriateness at the beginning of Inland searches.

Imagine a 10-by-10 mile target space, a perfect 100 square miles, where a search is initiated for a lost vessel. This can also be thought of as a checkerboard of 100 1-by-1 mile squares. The crew of a maritime search aircraft decides to use a sweep width of 1/8th of a mile (660 feet) with a lateral range of 330 feet on either side of the aircraft. At some chosen altitude, this provides a reasonably high POD or coverage. Dividing ten miles by 1/8th results in a requirement of flying 80 sensor tracks through the area. To be conservative, the crew adds 2 tracks to cover entry and exit at both ends of the 100 square mile box. Flying 82 ten mile tracks requires 820 flight miles. Adding 10 more miles, to account for the 80 eighth-of-a-mile shifts between tracks, results in a total of 830 miles. A turboprop or turbojet aircraft traveling at a stall-safe approach speed of 165 knots could search this 100 square mile area in about five hours. At faster speeds, in less than five hours.
[JRF – This paragraph reveals a fundamental misunderstanding of "effective sweep width." Apparently it is being confused with "track spacing," or the distance between adjacent tracks in a parallel sweep search. This is a common error among those to whom the notion of effective sweep width is new, especially if all prior experience has dealt with spacing, instead of "detectability" issues. Effective Sweep Width (***W***) and track

spacing (***S***) are ***NOT*** the same things. No one decides to use a sweep width of any value. It is not under the search planner's control. Sweep width is determined from tabulated values that were produced from detection experiments similar to those now underway for land SAR.]

[JRF – Let's suppose the lost vessel is a 16-foot outboard boat, that the meteorological visibility in the search area is 10 nautical miles, and the search craft is a helicopter flying at an altitude of 1500 feet. The uncorrected sweep width for this situation is 4.5 nautical miles, as obtained from the sweep width tables in the *IAMSAR Manual* or the *U.S. National SAR Supplement* thereto. If it is a calm day, the search speed of the helicopter is 90 knots and crew fatigue is not a factor, then this is also the "corrected" sweep width since no corrections are required. This means that as the helicopter flies along, the probability that it will detect the 16-foot boat if it is outside a 4.5 nautical mile swath centered on the helicopter's track equals the probability that it will miss (fail to detect) the boat if it is inside that swath. If the helicopter is assigned a track spacing of 4.5 nautical miles for a parallel sweep (PS) search pattern, the coverage factor is 1.0 for a rectangle with a width of 9.0 nautical miles (twice the track spacing because two search legs give the closest fit to the original 10 x 10 square). Since search conditions are basically ideal, the "ideal conditions" POD vs. Coverage curve is used and a POD of about 78% is estimated. If a track spacing of 5.0 nautical miles is used to cover the whole 10x10 square area using two search legs, the coverage would be 0.9, the POD would be about 73% and the search would require roughly 15 minutes of flying time. (I'm doing the table lookups, minor computations and reading of the POD vs. Coverage graph faster than I can type these words, by the way—it's that easy.) If conditions were worse with 15-25 knot winds, 2-4 foot seas, etc., then the effective sweep width is cut in half to 2.25 nautical miles using the "correction factor" for these conditions that is also found in the *IAMSAR Manual* and *U.S. National SAR Supplement*. In other words, the boat will be only half as detectable under these conditions as under calm conditions. If the track spacing remains 5.0 nautical miles, the coverage will only be 0.45 and the POD will be only about 36% due to the combined effects of a lower coverage and the need to shift to the "normal conditions" POD curve—the same curve that is recommended for land search for a number of very sound reasons. A 2.5 nautical mile track spacing for four tracks would boost the coverage back up to 0.9 for a POD of about 59% using the "normal conditions" POD vs. Coverage curve (which is always lower than the "ideal conditions" curve). However, the search in this last case would require about 30 minutes, which represents the doubling of effort required to get the same coverage when the sweep width ("detectability") is only half as large as in the other case.]

[JRF – A sweep width of 1/8 (0.125) nautical mile corresponds more closely with searching for a person in the water (PIW) under the above conditions. For ideal conditions, the sweep width is about 0.1 nautical miles. For the deteriorated conditions, the sweep width is about 0.05 nautical miles. Probably a different type of search pattern, called a sector search (VS) would be used in practice. However, if a PS pattern were used and the helicopter could actually maintain a track spacing of only 0.1 nautical mile, then it would take about 100 tracks or about 1,000 track miles to cover a 10 x 10 nautical mile square. At 90 knots this comes out to about 11 flight hours (which would require 3-4 helicopters depending on their fuel endurance and assuming they can re-fuel near the search area just before they start searching). For an object as small as a PIW, the "normal conditions" POD vs. Coverage curve would be used even for otherwise "ideal" search conditions and a coverage 1.0 search would produce a POD of about 63%.]

Compare this to planning an Inland grid search of 1 square mile. Using standard ISAR planning formulas **[5]** with twenty foot spacing (a lateral range of ten feet on either side of the observer), a reasonably high POD or coverage could be expected. Allowing for two sweeps per operational period, one mile up and one mile down, 132 trained responders would need to deploy for seven hours, to grid search a 1-by-1 mile square.
[JRF – Actually, given only this information, there is no way to know how much effort (how many responders) will be required to obtain any given POD value. It is clear that with current methods this is all guesswork. On the other hand, if the effective sweep width were known, then the POD for a 20-foot spacing could be easily estimated and we would know whether it was "reasonably high" or not. In open terrain or even open woods, the effective sweep width would probably be much greater than 20 feet and it would be obvious from the POD vs. Coverage curve that the POD was more than "reasonably high" (whatever that means). It would also be clear whether effort was being wasted on attaining a ridiculously high coverage. Going the other way, in thick underbrush, the 20-foot spacing might produce a POD less than "reasonably high." Again, if we knew the effective sweep width from detection experiments performed in the different environments, we would have an objective basis for estimating the PODs we could expect from this type of search in those environments and do a better job of allocating the available search effort.]

[JRF - We could also objectively estimate the POD we could obtain from a 3-person team using a "loose line abreast" or "wandering" technique if we knew the effective sweep width, how far they traveled while searching in the segment and the segment's area. Also, searchers should not scan only to a point halfway to the adjacent searcher track, but should scan a wider swath. The "one glimpse" visual POD is very much a function of distance, and the greater the distance, the lower the chances of a detection. Therefore, some "visual overlap" should be allowed to ensure the cumulative effects of two searchers looking at the space between them produces a reasonable chance for detection by one of them. Otherwise, the detection probability mid-way between searcher tracks may be at or near zero.]

To grid search 100 square miles, like the maritime example, in a similar timeframe at an estimated speed of one mile every 3.5 hours, the manpower requirement is astounding: 13,200 grid-searchers for seven hours! **[6]** Even spreading out these deployments over a week, 1,886 trained and rested grid searchers would need to be activated everyday. Clearly, ISAR units cannot provide this absurd level of manpower for extensive grid searching. ISAR needs to rely on non-grid search paradigms to compensate for its lack of speed in its human sensors and its inability to field a small army of trained responders at every emergency.

Is it unfair to compare a 100 square mile Search Area in MSAR to one in ISAR? We think not. Consider how long it takes a missing hiker to create a 100 square mile theoretical search area. A standard planning speed for a lost person is two miles per hour. Even at 25% of this figure, a lost hiker traveling at one-half mile an hour, for twelve hours on a summer day, could easily wander six miles away in a half-day. Using the formula for the area of a circle, pi times the radius squared, a six mile radius from the subject's Last Known Point or Point Last Seen creates a circular theoretical search area of about 113 square miles, in just half a day! A thorough grid-search of 113 square miles would require something on the order of 105,000 searcher-hours (15,000 searcher deployments times seven hours each). An MSAR aircraft over the ocean can do, in less than a normal workday, what it would take an inordinate number of inland grid searchers a week to do at a 24/7 operational intensity. Wandering off at two mph, this same hiker could create a theoretical search area of over 1,800 square miles in that half day, increasing the manpower requirement by a factor of sixteen.

This reinforces our conviction that it is inadvisable to encourage ISAR to adopt gridsearching as the primary technique for finding the living. While painstakingly thorough, it is both highly inefficient and virtually impossible to man at levels that will provide a quick rescue rather than the drawn out recovery of a cadaver.
[JRF – The entire argument given above is based on the false premise that the proponents of an improved conceptual base for search planning are fixated on close-spaced grid searching. I know of no one who advocates close-spaced grid searching as the primary technique. Anyone who suggests otherwise has missed the whole point of what we are suggesting. The fixation seems to be on the other side as an excuse for not seriously considering the improvements that are being proposed.]

Over the years, ISAR has developed a host of methods that emphasize efficiency over thoroughness to compensate for low searcher (sensor) speeds. Techniques like signcutting, binary sectioning, K9 scent detection, are part of an ISAR toolbox designed to use the least amount of manpower (and dog-power) in the most efficient way. Because speeds are slow and manpower is scarce, shifting to grid-searching within a closed search area, as the primary detection method, would be an unfortunate step backward.
[JRF – Again, the proponents of change are being grossly misrepresented. No one is recommending going back to the bad old days of marching through the woods shoulder-to-shoulder. Sign cutting, when done by a skilled searcher (preferably a tracker) is a good early tactic. It requires relatively little of the available effort and if sign is found, it can greatly reduce the length of a search by transforming a search problem into a tracking problem. The difficulty comes when the failure to find sign is interpreted as a 100% confirmation that the subject did not come that way. In most cases such high confidence in a negative search result cannot be justified. The same goes for binary sectioning. Use of air scenting dogs is fine, but often not very reliable from what I have heard. When

they make a quick find, it is great, but when they do not, segments cannot be ruled out on the basis of negative results. In most cases, at least one more search by a different resource is probably justified if there is any reasonable level of probable success rate to be had there.]

[JRF – The techniques of hasty search, establishing a direction of travel, finding a subject's track that can be followed, various investigative techniques, confinement, use of lost person behavior statistics, etc. are all valid things to do and no one is arguing otherwise so far as I know. The proponents of a proper application of search theory to area searches, when they must be done, do not mention these other techniques simply because their value is obvious, well-established, and is not being challenged. We sincerely regret if this lack of mention has been misinterpreted to mean that we intended to recommend discarding them.]

Topic 3: POA vs. POD

Some SAR practitioners have a shown a bias toward POD over POA. Their reasoning centers around the idea that the efficiency of the sensing resource, expressed as POD, takes precedence over the locational likelihood of the subject, expressed as POA, in driving up POS.
[JRF – The classic problem in all search planning, whether on land or water, is finding the optimum balance between covering more area (higher POA) at a lower coverage (lower POD) and covering less area (lower POA) at a higher coverage (higher POD). This problem has a proven solution from search theory. In fact, a uniformly optimal search plan maximizes the POS in the minimum time. In short, it solves the problem, "How do I apply the available resources to maximize the chances for finding the subject in the shortest possible time?" It turns out that the solution does not depend on POA or POD alone, or even both taken together. Probability density, search object detectability, and search speed in each of the segments where resources could be sent all play a role as well.]

Table 2 below shows the true distribution of POA in a 4-segment closed search area. Regardless of any initial consensus or empirical distribution, the subject, marked by an "X" can only be in one of the segments with a true Probability of Area of 100%. All of the other segments have a true POA of zero.
[JRF – The use of the term "true POA" is unclear. If the subject is in the search area, then the subject must be at some specific location. That is not a probability but a certainty and it applies only to subject's exact location in time and space, not to some arbitrary area that contains the subject's location. This type of imprecise thinking would undoubtedly lead to poor marks in any elementary statistics course.]

Table 2: True POA in a 4-Segment Search Area

X 100%	0%
0%	0%

A poor resource with a low POD still has a chance of finding the subject if deployed in the segment where the subject is located. A perfect resource deployed in an area where

the subject is not located has a zero chance of a successful find. Consider the following imaginary problem: a family member is missing and the Incident Commander asks for your preference. He can deploy resources to the Moon with 100% POD, or he can deploy a very poor resource into the area where the family member was last seen. Obviously, we would all intuitively prefer the second choice.
[JRF – This "argument" makes no sense. I'm sure no one has recommended deploying resources to any places on earth, much less the moon, that have zero POA. This situation as it is described has no bearing on the issues at hand.]

While the choice may seem obvious, certain search priority schemes create a bias toward the resource POD and away from the POA. Is it better to search in an area with high POA or with a resource that has high POD? To look at the problem from another angle, Table 3 shows an example of two POA x POD interactions that produce the same POS. Which would you choose? Assume that the same resource is used but with a different POD per segment.
[JRF – Please demonstrate the alleged bias. What optimal allocations do is ***remove the bias*** toward either POA or POD. The argument given here supports a POA bias at the expense of POS, which could easily delay or even prevent detection.]

Table 3: Mathematically Equivalent POS

Segment	POA	POD	POS
1	90%	10%	9%
2	10%	90%	9%

In the first example, the likelihood of the subject being in the segment is high, while the resource only has a 1-in-10 chance of making a find. In the second example, the probability that the subject is in the area is relatively low (given only the two segments), but the resource is highly efficient, expected to have a find nine out of ten times. Note that these two situations produce the same POS. Mathematically they are equivalent, but is one to be preferred over the other?
[JRF – There is insufficient data given, but if these figures are to be believed, and each segment search requires equal time to complete, and within each segment the probability density, search object detectability and search speed are all uniform across that segment, the correct answer is "No."]

We would argue that the first case should be preferred. Although the resource is poor in Segment 1 and excellent in Segment 2, it should nonetheless be deployed into Segment 1. The rationale for this is twofold: First, the purpose of a search is to find the subject as quickly as possible, not sweep the entire search area as quickly as possible. These goals are not the same and may have different starting points. The subject is more likely to be found by any resource in Segment 1.
[JRF – On what basis is this assertion made? There is certainly no scientific support of which I am aware for such a preference. Just because there is a higher POA does not mean the subject will be found any more quickly. If each segment requires the same amount of time to search and conditions within each are uniform, then the POS vs. elapsed time curve will be the same in each of the cases described. Look at it this way. There are a total of 100 objects between the two segments. In Segment 1 there are 90 uniformly distributed objects (POA = 90%), of which 9 (POD = 10%) will be found. On average, one object per hour will be found. In Segment 2 there are 10 objects (POA = 10%) uniformly distributed, 9 of which will be found (POD = 90%). Assume it also takes 9 hours to complete this segment. On average, one object per hour will be found. In both cases, 9 objects were found in 9 hours. There is no difference.]

Secondly, the POD of the resource, whenever it is in the segment where the subject resides, is likely to be higher than its calibrated value. This is due to serendipitous elements of chance that work in the resource's favor: the resource may simply get lucky and stumble onto the subject; the subject may have left strong clues or signs, or the subject may be actively looking for rescuers.
[JRF – This is a dangerous and obviously biased assumption. Please cite independently verified scientific research and data to support this claim. So far, I have seen nothing in

the scientific literature that lends support to such an assertion. The resource (or more correctly the subject) may just as simply get unlucky and the resource will pass the subject at close range without detection. The subject may have left few clues and signs, or none at all from the direction of the resource's approach. The subject may be non-responsive. Basing effort allocation decisions on a string of "maybes" all biased in the same direction does not seem to be an unbiased or wise way to do business.]

For these reasons, we would discourage the use of search priority schemes that bias deployment toward areas of high resource POD but low POA.
[JRF – There is absolutely no reason to favor POA over POD. On top of that, several critically important variables are not even being considered here. These include search speed, detectability (a function of sensor, search object and environment), and segment size, all of which contribute to the probable success rate of resources that could be assigned.]

Topic 4: TDA's: Tactical Decision Aids

Tactical Decision Aids are computer programs that assist with search management tasks related to probabilistic assessments and the associated Bayesian mathematics. The Coast Guard uses Computer-Assisted Search Planning (CASP), a proprietary application that starts by running a Monte Carlo simulation of 10,000 iterations to create an initial probability distribution for cells in a closed search area. The US Navy uses a proprietary multi-target package called NODESTAR, capable of generating up to a half-million 6-dimensional cells to account for characteristics like depth, velocity and target type. [7] These applications are not available for use by Inland SAR planners.
[JRF – CASP uses 20,000 simulated search objects ("replications" or "reps") per scenario, where each scenario is defined by a logically consistent set of "locations" and a single search object type (e.g., a life raft). Multiple scenarios are allowed.]

Inland SAR currently has a handful of TDA packages available. The two best known IBM-PC compatible applications are CASIE (Computer-Aided Search Information Exchange), which is free, and Search Manager which costs in the range of $750 plus fees for additional seats. Of the two, CASIE is the simpler to use. Search Manager, which does a host of SAR planning and management tasks, including the ability to connect across an agency's entire network, is not typically run by a single user and is a complex system to learn.

The controversial nature of this topic lies in the fact that proponents of MSAR techniques in ISAR do not recommend (or even mention) either CASIE or Search Manager as viable TDA's. We suspect that this is because both include ROW in their POA distributions. MSAR proponents seem wedded to the idea that ISAR must revert to closed systems with no ROW, in spite of the fact that the use of ROW is a mathematically acceptable practice, if not widely implemented, in Operations Research.
[JRF – I have mentioned CASIE several times on the SAR-L list and in several reports to the National Search and Rescue Committee. Its use of R.O.W. was not considered particularly debilitating, just without significant benefit and unnecessary. CASIE's failure to display the cumulative overall POS, which it computes and uses, and its offering of R.O.W. in place of this extremely useful value, was considered a significant shortcoming. However, the greatest shortcoming was the GIGO principle—garbage in, garbage out. If the POD values entered are objectively determined using the procedures recommended by the proponents of progress, CASIE will correctly determine which allocation of resources among all possible resource/segment/POD combinations contained in the inputs produces the highest POS.]

[JRF – However, there are two problems: First of all, land SAR has no objective method for estimating POD as a function of effort expenditure, or even estimating effort itself—just subjective guesses at POD values. Second, there is no guarantee that the best possible combination of resources/segments/PODs will be contained in the inputs. Instead of just putting all the pertinent information in the hopper and having CASIE churn out where resources should be placed and in what concentrations to maximize the cumulative overall POS, the user has to partially allocate the effort ahead of time by deciding, for example, that segment 1 will get either three searchers assigned or five searchers assigned, but not four. Four might turn out to be the ideal level for that segment, given all the other factors in play. However, CASIE cannot produce that answer since it is not in the list of possible search assignments. In short, CASIE has serious limitations, some of which are its own fault but many of which are the fault of poor and incomplete understanding of how to apply search theory correctly and effectively to the land SAR search problem.]

Oddly enough, the impact of this is to take computing power out of the hands of ISAR planners, as MSAR proponents now recommend the retrograde use of paper forms for tracking and calculating POA updates. MSAR proponents have bemoaned the "computational burden" imposed by ISAR calculations, never overtly mentioning that CASIE has been around almost a quarter century to do them. As Alan Washburn notes, "CASIE3 is a user-friendly TDA that has been well received in the Inland SAR community, and which reliably shifts the POAs to account for past search effort." [8] [JRF – Again, we are being grossly misrepresented. The general hue and cry that has reached our ears is to make everything simple enough for pencil and paper. Many seem to distrust computers. Many others say they are impractical to carry into the field and are reluctant to depend on an electronic device with batteries that last only a few hours under continuous use. Not everyone, apparently, has a well-appointed mobile command post with generators, etc. We would like nothing better than to see appropriately programmed computers in wide use with user-friendly interfaces (which CASIE3 is not by today's standards). In fact, I'm consulting on several projects to do just that, mostly pro bono. More importantly, all the computations that are the subject of so many complaints can be hidden from the search planner's view. But before this becomes truly feasible, we have to make sure the basic concepts are correct and well-understood. Without such understanding, users cannot make effective use of even the best software. The worst thing we could do is program computers to make the mistakes now in the land SAR literature at the rate of billions of times per second.]

It is as though MSAR proponents are insisting that ISAR borrow its techniques but not the computing power required to properly implement them.
[JRF – This is absolutely untrue, not to mention inflammatory. See above.]

Topic 5: Mattson Consensus vs. Initial Distribution

In our view, the most misplaced idea from proponents of MSAR techniques is the equating of a Mattson Consensus, as developed in ISAR, with an Initial Distribution, as developed in MSAR. Similar to imposing on ISAR the grid search as a primary detection technique, using a Mattson Consensus improperly is a mathematical blunder.

Each formal search, where POA is going to be tracked and updated, must start with either an Initial Distribution or a Consensus. In maritime searches, the US Coast Guard employs the CASP software to create an initial probability distribution. This is done by combining a sample of empirical data, how lost vessels behaved under various environmental conditions, and using Monte Carlo analysis to create a set of probabilities based on the sample inputs. As previously noted, CASP runs 10,000 randomly seeded iterations to produce the probability distribution needed to create POA values for every cell in the closed search area. This is a rigorous method for creating POA assignments. Nothing like this currently exists in the Inland SAR world.

ISAR planners use a Mattson Consensus, named after its inventor, Colonel Robert Mattson, USAF, to create a pseudo probability distribution. Since a rigorous method for creating an initial distribution was not, and still is not, available to ISAR, Col. Mattson devised a weighting scheme that would rely upon the opinions of individual experts, people familiar with aspects of a search like local terrain and typical behavior of the category of lost person. There was never any pretension that these were true, empirically derived probabilities. But they acted as a starting point to avoid paralysis and get the search going. Without a Mattson Consensus, all segment probabilities would be equal, leaving no clear indication where to send resources first.
[JRF – Again, this assessment shows an incomplete understanding of the purpose and use of POA. Even with a Mattson Consensus, there is still no clear indication of where to send resources first on the basis of the POA values alone. There are other equally important factors to consider and the fact that land SAR does not consider them is the greatest conceptual and mathematical blunder of all. There is nothing wrong with a subjective estimate of a probability density distribution, which is what a Mattson consensus really is. As mentioned earlier, even the inputs that go into CASP to generate probability density distributions have a good deal of subjectivity in them. It cannot be entirely avoided.]

In MSAR's closed search areas, which are effectively devoid of clues (remember, no footprints left on the water), the initial distribution is a critical metric that often guides the search from start to finish. In ISAR, the initial consensus is just a qualitative estimate that can be shifted quickly in the presence of a strong clue. Indeed, we would assert that in ISAR, a strong clue is far more important than the initial consensus. After all, a Mattson Consensus is only the weighted average of a series of best guesses. Unlike a rigorously

derived probability distribution, the quality of the experts' opinions cannot be controlled from search to search.
[JRF – Again, maritime SAR procedures and techniques are being grossly misrepresented. There may be no footprints on the water, but there is debris, and there are a host of clues discovered by investigative techniques which, while they do not reside in the search area, are just as important as those that do. In maritime SAR, initial probabilities can be and often are quickly shifted in light of new information. Old scenarios may be thrown out and new ones created. Scenarios may be re-weighted on the basis of new information. A new strong clue is just as important and taken just as seriously in maritime SAR as in land SAR. Scenario development and weighting is an essentially subjective, human process that is quite similar, in general concept if not in terms of implementation, to a Mattson Consensus. The mathematical rigor of maritime SAR initial distributions is limited to how they are constructed around subjectively determined points and lines, and in subjectively determined operational areas.]

[JRF – The statement that the initial consensus can be shifted quickly contradicts earlier statements that imply the finding of new clues does not require a new consensus.]

Proponents of MSAR techniques in ISAR mistakenly give a Mattson Consensus the same weight as a rigorously derived Initial Distribution. If a closed system is used, the initial cell or segment probabilities have to be locked down at the start of the search. In a clue rich environment like ISAR, this means that an entirely new consensus would have to be developed every time a strong clue was found within or without the search area.
[JRF – Again, this "closed" vs. "open" comparison is a complete red herring. Cell or segment probabilities do not have to be "locked down" at the start of a search. Please cite the source on which this assertion is based. If the situation is not being re-evaluated every time a strong clue is found, then a serious breach of "best practices' is being committed. Since the consensus method is used for the initial evaluation, it seems logical to use it for all re-evaluations as well if it is indeed a valid process. If it is not a valid process, then some other evaluation technique needs to be developed.]

Furthermore, the substitution of a Mattson Consensus for an MSAR-type Initial Distribution, provides a false sense of precision. A Mattson Consensus is neither empirically nor probabilistically derived and should not be used within a closed system. At the moment when a Mattson Consensus is developed, ISAR planners have, relative to the search's timeline, virtually the least amount of information about the lost subject's whereabouts. In MSAR, the Initial Distribution, based on the physical properties of a vessel and forecasts for the surrounding environment, is quantitatively derived and may constitute most or all of the pertinent information available to planners for the duration of the search.
[JRF – Every SAR case, maritime or land, starts in an information-sparse environment. I don't know where the idea comes from that maritime SAR has it any easier than land SAR in this regard. No maritime search planner should consider CASP distributions as "precise" in any sense of the word. Just because a computer is used as an aid to an

essentially subjective start-up process does not mean the results are any more precise. The Mattson Consensus provides, for search planning purposes, the means to get an exact mathematical equivalent of a probability density distribution from CASP. Were it not for certain programming issues (that actually should not be there), CASP could be used on land and could represent segments, POAs, and all the other factors involved in planning optimal searches, including many not currently in the land SAR tool box. A Mattson Consensus would be a perfectly valid input in cases where the "standard" statistical distributions used for maritime SAR do not apply. Regardless, new information that sheds new light on the situation must be accounted for and appropriate changes made to the initial probability density distribution.]

We assert that the use of a qualitatively derived Mattson Consensus as a surrogate for a quantitatively derived Initial Probability Distribution is a serious flaw in the effort to standardize lSAR with MSAR techniques. The use of a closed system bestows a misleading level of accuracy on Mattson derived initial POA distributions, by equating them with mathematically rigorous ones.
[JRF – This is not true and it appears to be a case of raising an objection purely for the sake of objecting to alternative approaches. As Koopman pointed out, one of the essential elements in search planning is a probability density distribution on search object location. If one cannot assume that one of the standard statistical distributions is adequate, there is still a requirement to develop a probability density distribution on search object location, even if it means using a Mattson Consensus or other purely subjective technique that preserves the essential nature of the consensus team's assessments—namely that the proportionalities among POA values actually reflect those assessments.]

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APPENDIX A
Grid Search Calculations

1. For determining the number of searchers required, 1-Square Mile

Assumptions:
SA = 1 square mile
Searcher Speed = 1 mile per 3.5 hours
Searcher Spacing = 20 feet (lateral range of 10 feet either side)
Duration = 7 hours (allows 1 mile up & 1 mile back)

Searchers = (Area sq mi x 5280 x 3.5) / (Spacing in Ft x Hours)

= (1sq mi x 5280ft/mi x 3.5hrs/mi) / (20ft x 7hrs)

= (18,480/140)

= 132

2. For determining the number of searchers required, 100-Square Miles

(132 searchers/1 sq mi) * 100 sq mi = 13,200 searchers

3. For determining the number of searchers required Daily for a Week

13,200 searchers / 7 days = 1,886 searchers per day

4. For determining the Theoretical Search Area at 2 mph for 12 hours

2 mph * 12 hours = 24 mile radius
pi * (24 mile radius Squared) = 3.14 * 576 = 1,809 Square Miles