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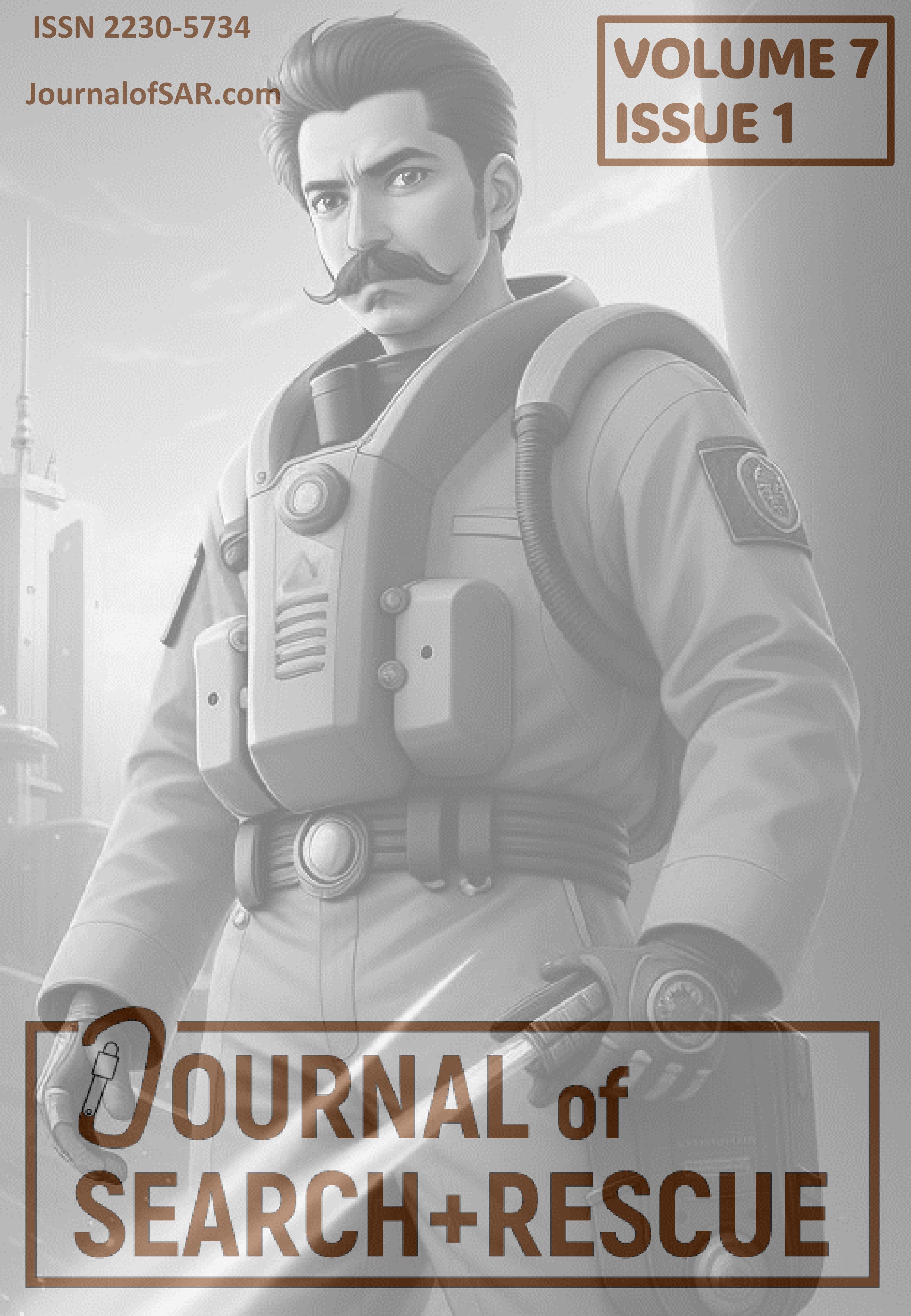

JOURNAL of SEARCH+RESCUE

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JOURNAL of SEARCH+RESCUE

The Journal of Search and Rescue (JSAR) is an open access peer-reviewed electronic journal for the collation and distribution of original scholarly material on search and rescue (SAR).

It is being supported by the in-kind work and contributions of the Editorial Board. There is still the need for a dedicated journal serving those with a direct interest in all disciplines of search and rescue including: rope rescue, water (flat, swift and marine), ice rescue, wilderness search and rescue, structural collapse rescue, trench collapse rescue, cave rescue, dive rescue, motor vehicle extrication, canine search, technical animal rescue, air rescue, search theory, search management, and mines rescue. JSAR exists to fulfil that need.

Article submissions from these and other SAR disciplines are welcome. Launching this journal on the internet offers a relatively cost-effective means of sharing this invaluable content. It affords the prompt publication of articles and the dissemination of information to those with an interest in SAR.

JSAR will provide a forum for the publication of original research, reviews and commentaries which will consolidate and expand the theoretical and professional basis of the area. The Journal is interested in theoretical, strategic, tactical, operational and technical matters.

Advertising within JSAR will be considered in the future to ensure sustainable funding is available to enhance and continue the work of the journal. The publication of an article in the Journal of Search and Rescue does not necessarily imply that JSAR or its Editorial Board accepts or endorses the views or opinions expressed in it.

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Cover Image: An AI Image of a futuristic SAR technician.

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Editorial

Welcome to Issue 1 of the 7th Volume of the Journal of Search and Rescue.

Readers will have noticed, in the previous pages, that this issue contains for the first time a list of our corporate partnerships and affiliations. In the last issue, we announced our partnership with the Institute of Civil Protection and Emergency Management (ICPEM) and published a guest editorial from their President.

This resulted in two benefits for this journal. The first is that ICPEM are sponsoring the production of digital object identifiers DOIs for all articles published in our Journal. This has meant that papers published here are now referenced in all major international libraries and cross-referenced for their discussion in in other publications. The result of that is that many of our contributing authors have seen their research rankings improved, as well as an increased influence of Search and Rescue as a scientific discipline.

The second beneficial result was that a number of other relevant organisations contacted us to discuss alliances and affiliations with them and I'm proud to include a page in this issue sharing the details of such an illustrious collection of Search and Rescue Organisations. There are links below each logo, so please do visit them, and if appropriate, consider joining them as a member.

This issue is split into three parts. The first section is the typical contributions original research. We then have two letters to the editor, and two submissions to the annual Syrotuck Symposium held in Iceland in 2023.

Discussions of Artificial Intelligence appear in the articles in this issue, and did in the previous issue. In addition it is in evidence on the cover, where artificial intelligence was used to create a futuristic Search and Rescue technician.

Artificial Intelligence often suffers from a bad press internationally with people (perhaps justifiably) concerned that without adequate controls there may be risks to humanity. In addition, people are reasonably concerned that artificial intelligence may replace them at work and that our social and economic systems have not developed adequate protection for workers replaced by artificial intelligence. Although these concerns are legitimate, I prefer to see artificial intelligence as an opportunity rather than a threat - especially in the realm of search and rescue.

The ability to tap into many centuries of knowledge and experience in seconds when planning conducting or analysing data relating to a search has enormous potential for our sector. Admittedly, some of the same concerns may exist, in that we may need fewer search planners if artificial intelligence becomes reliable enough, but this is the same with all advances in technology. I would argue that in our sector where it literally is a matter of life and death, and where lives can be saved with the application of the correct technique and technology, then we should never fail to overlook any potential incremental improvement in our performance.

Our sector is undergoing a number of changes, and so is our Journal. Some changes are purely improvements, driven by our new corporate partnerships, and we will be looking for volunteers for editorial, social media, and administrative roles going forward. We will also, as always, welcome research common, commentary, and any other contribution from the search and rescue community. Please do get in touch if you feel you can contribute to the future of the Journal.

I often end editorials with a thank you to you the community; the researchers, the scientists, the practitioners of search and rescue, who regularly put themselves before others to save life, and those who dedicate their time, energy, and intellect to creating and submitting work for this journal. I appreciate that I do it often, but I assure you it is always heartfelt.

Stay safe - and thank you all for what you do.

Dr Ian Greatbatch

Worcestershire, England

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The Value of Searching by Voice in LandSAR

Rod Costigan M AppFin
Victoria
Australia
Email: rod@greenstock.com.au

Abstract

This study is concerned with off-track foot searching for a missing person who is presumed wanting to be found and who is by nature responsive.

The study explored the hypothesis that searching just by calling and listening is superior to any other on-foot methods, even though the missing person's responsiveness will decline over time.

Spreadsheet modelling has been used to calculate the comparative probabilities of success of various strategies, employing three common search methods either exclusively or in combinations.

Results strongly favour searching by calling and listening exclusively while the search objective is to save the missing person's life, that is, to ignore the possibility that the missing person is no longer responsive.

KEY WORDS: *LandSAR, missing person, search strategy, voice searching, Probability of Area*

Introduction

Off track foot searching is undertaken predominantly by sight, calling, and listening. Search methods that maximise emphasis on detection by sight are usually called Line or Grid Searching. Normally, detection by sound would be considered a windfall to such searching. Any method that seeks to optimise the use of sound, leaving detection by sight to good fortune, can be thought of as being at the other end of a spectrum of methods. Many methods have been devised that fall between.

Typically, search planners must use experience and judgement, together with medical advice to decide on the optimal search method or methods to employ. The search planners will be reviewing those decisions at every stage of the search to maximise efficiency and effectiveness. It would assist a search planner to know where on this scale lies the optimal search method, or combination of methods, at any point of time in a search operation. Further, a consideration in method selection is the search objective: either to save the missing person (MP) or to find the MP's remains. While the literature reviewed describes methods in detail, selection of methods as options in a strategy and its relationship to current search objective has received less attention.

The 2003 review of LandSAR literature for the U.S. Department of Homeland Security and the United States Coast Guard (Cooper et al, 2003) provides a concise summary of literature to that time. The authors provide some insights into strategy under the heading "Effort Allocation" but do not reference any direct empirical search method comparisons. The review is critical of preceding LandSAR studies relating to their treatment of Probability of Detection (POD) as applied to clues as if all clues are of equal detectability. However, the review does not extend this principle to missing persons (MPs) in different physical states.

Operations manuals provide a little more direction. In *Managing the Lost Incident,* (Hill et al., 2011), the authors devoted a chapter to Allocating Resources. Prominence was given to searching by widely spaced “Sound Sweeps” using whistles. In Cooper et al, 2003, the authors broadly divided detection methods into “indirect” and “direct”. “Indirect” refers to methods of drawing the MP to safety, e.g. sounding a horn, and “direct” referring to active searching. The search methods examined in this paper, *Voice in LandSAR,* would all be classified as direct searching. Hill et al, 2011 listed direct methods as Hasty Searching, Loose Sweep Searching and Tight Sweep Searching. While not explicitly included in this list, Sound Sweep was discussed at length and corresponds closely to the description of Loose Sweep Searching. Calculations in this paper, *Voice in LandSAR,* suppose use of the method of Voice Searching described in Appendix 1. This would similarly fall into the category of Loose Sweep Searching. Tight Sweep Searching explicitly includes Grid Searching, which mathematically closely approximates the Line Searching used for comparative purposes in this paper (*Voice in LandSAR).* Hill et al, 2011, then recommended employing one of these three categories at each of three distinct phases of a search: at the start; when thoroughness is required; and/or when other methods have failed. Loose Sweep Searching was described as suitable only while the MP is likely to be responsive. However, no consideration was given to any relationship between selection of method and search objectives.

Also published in 2011, and probably the most influential LandSAR manual, is the *Addendum to the National Search and Rescue Supplement to the International Aeronautical and Marine Search and Rescue Manual V1* of the [UN] National Search and Rescue Committee (2011). In its description of search methods, the structure of the Addendum closely resembled that of Hill et al, 2011. In relation to selection of methods, the Addendum offered only that Rapid (Hasty) Searching comes first and rarely extends far from the Last Known Point (LKP). Sound Sweep was given less prominence than in Hill et al, 2011 but it noted that Sound Sweep is fast but relies on MP responsiveness. Neither was discussed in the context of search objective.

Another manual at the level of national application which is in the public domain and which applies to this author’s own region is the *National Search and Rescue Manual published by the Australian Maritime Safety Authority* (2019). This categorised LandSAR methods as “Fast/ Reconnaissance”, “General Search” and “Contact Search”. Nine patterns of “Contact Search” are described. Diagrams imply, though the text did not state, that eight, or possibly nine, of the “Contact Search” methods are primarily sight-based searching. Among them, “Parallel Sweep” and “Creeping Line Ahead” correspond most closely to the methods known more widely as Grid Searching. The Manual did not describe methods of “General Search” in detail. Sound Sweep was referred to but was not discussed; neither were other methods of searching primarily by sound. It advised the circumstances which might suit each General or Contact method but not in a comparative sense.

In essence, these sources provide, or refer to, search techniques that a search planner can use, but relatively little guidance on how to optimise their use for the circumstances of a search.

Further, search literature does not typically make a distinction between search strategy for finding a person alive versus a strategy for finding the MP in any condition. Hence the concept of Probability of Success (POS) is widely used without a definition of Success, the implication being that it refers to finding in any condition (which this paper terms POS_{fin}). Any analysis that focusses on POS needs to define Success. This paper applies two definitions, POS_{fin} and POS_{sav}, being the probability of saving the MP's life. The study assumes that the search planner will attempt to maximise POS_{sav} exclusively until a threshold at which probability of survival is low enough to justify switching to a focus on POS_{fin}; this study makes no assumption as to what that threshold should be.

This study explored the hypothesis that Voice Searching (as defined in Appendix 1) alone is a superior method to any other on-foot method that uses sight, voice, and hearing, for an MP who at time of disappearance was responsive and presumed wanting to be found. It did this in relation to POS_{sav} and POS_{fin}, while focussing primarily on $POS_{sav.}$

The very simple analysis that follows suggests that searching by voice might offer a such an advantage over searching by sight as to make the choice of methods for MPs who are responsive by nature more straight forward than is generally recognised.

At its most simplistic, a comparison of the effectiveness of searching by voice as a primary medium (Voice Searching) versus searching by sight as a primary medium (Line/Grid) can be made by a simple logic:

$$P_{res} \text{ x } S_{voice} \approx POS_{sav(voice)}$$

$$P_{alive\ non} \text{ x } S_{line/grid} \approx POS_{sav(line/grid)}$$

Where:
P_{res} is the probability that the MP is responsive at a given point in time,
S_{voice} is the speed of searching exclusively by voice measured by land area over unit time,
$POS_{sav(voice)}$ is the probability of saving the MP while searching entirely by voice,
$P_{alive\ non}$ is the probability that the MP is responsive at a given point in time,
$S_{line/grid}$ is the speed of searching exclusively by sight measured by land area over unit time,
$POS_{sav(line/grid)}$ is the probability of saving the MP while searching entirely by sight,
and for this purpose, it is assumed:

that Voice Searching never finds an MP who is unresponsive,
that Line/Grid Searching never finds an MP who is responsive, and
that all searching is at a POD of ~100% for a responsive or unresponsive MP respectively.

Suppose that on balance an MP would be expected to spend 4 times as long responsive as alive but unresponsive. Regardless of the rate of the MP's decline in health, the probability that the MP is responsive starts high but settles down to:

$$P_{res} = 4 \text{ x } P_{alive\ non}$$

Also suppose that:

$S_{voice} = 15 \times S_{line/grid}$

Then it follows that:

$POS_{sav(voice)} \approx 60 \times POS_{sav(line/grid)}$

According to this simple analysis, searchers will be about 60 times more likely to save the MP in any specified period of time if they are Voice Searching than if they are Line/Grid Searching. This is regardless of how long the MP has been missing. Any method which compromises the use of voice for greater use of sight, or vice versa, should offer a probability of saving the MP somewhere in between the Voice Searching and Line/Grid Searching.

This simple analysis ignores all the complexities of real life searching and search planning. To test the hypothesis with major complexities factored in, MS Excel was used to model a hypothetical search.

Method

The model examines a hypothetical search over four days. The hypothetical search planner has an opportunity to reassess strategy at the start of each day.

The Model

The Search Area

A hypothetical Search Area was divided into four segments with a total Probability of Area (POA) of 95%, the remaining 5% being in the rest of the world. This can be visualised as concentric circles or squares. However, shapes and alignments of segments are not relevant to the calculations that follow.

Strategy

The model allows the hypothetical search planner to select one or two search methods to be applied each day and across any segments. One permitted method is Line Searching to a target 100% POD for a prone, silent person. The other is a choice of Voice Searching, utilising the method described in Appendix 1, and Feature Searching; a method that combines/divides emphasis of sight and sound, as described in Appendix 1.

Calculating Probabilities

The model calculates the Probability of Success (POS) of a strategy at the start of the search and at the start of each day in view of the presumed failure of previous searching. It does this for the objective of saving the MP and again for the objective of finding the MP as quickly as possible, surviving or not.

To perform the calculations, the model uses the common method of assuming 100 MPs whose description and circumstances are identical, but who in every unseen respect are randomly different people. Counting the fates of the 100 MP's is arithmetically simpler than calculating conditional probabilities relating to a single person, is simpler to visualise, and it yields the same arithmetic outcomes.

The model tracks the number and distribution of remaining responsive MPs, alive unresponsive MPs and deceased MPs through the four days. This is equivalent to progressively recalculating POAs.

Real world complications and their treatment

All searchers are bi-modal.

'Bi-modal' refers to searching simultaneously by sight and radar (Koopman, 1946). Similarly, foot searchers are essentially bi-modal, searching by sight and sound.

The opening proposition ($\mathrm{POSsav}_{(voice)} \approx 60 \times \mathrm{POS}_{sav(line/grid)}$) assumed that Voice Searching achieves 100% POD by sound and nil detection by sight, and that Line/Grid searching achieves 100% POD by sight, and nil by sound,. Table 1 shows the Base Case assumptions used in the model, based target PODs of 100%.

	POD_{res*}	$\mathrm{POD}_{non\text{-}res*}$	Team speed		No.Teams
Feature Search	90%	10%	0.25	km^2 searchable in one day, measured by voice reach	8
Voice Search	99%	5%	1.00	km^2 searchable by voice in one day	
Line Search (only)	99%	99%	0.067	km^2 searchable by sight in one day	
Line Search (following)	0%	99%	0.067	km^2 searchable by sight in one day	

**Probability of Detection for a responsive MP*
***Probability of Detection for an unresponsive MP*

Table 1 – Base Case assumptions: PODs, speeds and workforce

If there is any prospect of the MP being responsive at the outset, Line or Grid Searching will only be employed where a search method using sound has preceded it (Line/Grid Search (following)), thus resulting in an effective POD_{res} close to zero. In this analysis, Line/Grid Search (only) might have relevance later in a search if search planners have abandoned the prospect of the MP responding and are searching new ground.

Fast searchers are soon searching areas of lower Probability Density (PDEN) and therefore quickly become less productive.

Rarely would PDEN, a segment or sub-segment's POA per unit area, be uniform across the entire search area. Voice Searching is a faster method, so moves into areas where it is assumed that the missing person is inherently less likely to be. The model accounts for this by dividing the search area into segments of declining PDEN. Segments can have any configuration, however, those used in the model's base case (Base Case) (Table 2) are consistent with a bullseye pattern of concentric segments.

Segment	Area (km^2)	POA
Segment 1	2	50%
Segment 2	6	25%
Segment 3	10	15%
Segment 4	14	5%
ROW		5%

Table 2 – Base Case assumptions: Segment areas and POAs

The MP's condition changes.

The assumptions about change in the MP's condition must describe how the MP is most likely to decline irrespective of the search, i.e. these assumptions will not be influenced by the progressive success or failure of the search.

Table 3 displays the hypothetical schedule of condition decline used in the Base Case. This assumes that organised searching commences half a day after the incident begins and that the ratio of responsive to unresponsive alive MPs is 4:1 and the daily survival rate is 70% of previous day survivors.

Average time spent responsive / time unresponsive but alive.	4
Days between LKTime* and SOD1	0.50

Timeline	Daily survival**
LKTime*	100%
SOD1	90%
SOD2	70%
SOD3	70%
SOD4	70%
EOD4***	70%

** LKTime - the known or presumed time of commencement of the incident.*
*** Daily survival - the proportion of MP's who were surviving at previous end of day who are still surviving at next SOD*
****End of Day 4*

Table 3 – Base Case assumptions: Responsiveness and Survivability

For the purposes of modelling, it was assumed that all MP's are physically stable throughout the duration of each day of searching, and that a proportion lose responsiveness or decease between the end of a day of searching and before commencement of the next day of searching.

These numbers are speculative, therefore sensitivity to these assumptions was tested by halving the relative time responsive and doubling the overnight mortality rate.

Mobility

Mobility statistics from *Lost Person Behavior*, (Koester, 2008) indicate that most of the MPs become immobile (but not necessarily unresponsive) within the first 24 hours of going missing, rendering mobility of doubtful significance.

Notwithstanding, two methods have been applied. The first is to take the PDEN of the unsearched part of each segment at the end of each day, then to move that number anywhere between 0% and 100% towards the average PDEN of the whole segment. 100% represents a world in which the MPs move rapidly and randomly within their segment to the maximum degree possible, and 0% is where no-one moves. 100% represents losing as many MPs to previously searched ground as random travel can allow and 0% loses none. The Base Case uses 20% for responsive and 0% for alive unresponsive MPs. It is arguable that a value should be attributed to unresponsive MPs, but a value of zero is more conservative to the study's conclusions. This method ignores inter-segment movement, which is presumably less likely to occur.

The second, simpler approach applies an arbitrary loss factor to all segments at each end of day. This represents the percentage of responsive MPs and alive unresponsive MPs who will have alluded searchers for the remainder of the search by relocating to a searched area. The Base Case uses 10% for responsive and 2.5% for alive unresponsive MPs.

These numbers are entirely speculative. However, sensitivity testing was conducted to establish whether the range of numbers that might conceivably reflect the true incidence of mobility impacting search outcomes would impact on the study's conclusions.

The impact of clues

"Clues" can be expected to impact results because they favour sight-based searching methods.

In actual searches, there are presumably many more clues, typically of low detectability, than are found. There are also many which are found without significantly altering the outcome, for example, by advancing the MP find by a non-critical hour. Additionally, there are false clues which impede a search. To mimic the mathematical impact of clues, the model accepts an input that represents the percentage of MP finds in which a clue was found first that resulted in an improved outcome, in terms of the MP being found alive versus deceased or being found deceased versus not found at all. It was estimated that this accounts for 10% of successful outcomes. Each such clue is treated as equally detectable as an unresponsive MP. Negative impacts from false clues were ignored. The model inserts a number of clues into the search area, distributing them in proportion to the POA of each segment. It adjusts this number until a search that employs methods in a particular hypothetical pattern finds 10% as many clues as the total number of MPs and clues found. This hypothetical pattern is referred to as the Base Strategy and will be defined shortly. The model retains that same distribution of clues regardless of which search strategy it is testing.

Data to support the clue frequency estimate will always be difficult to source. This is due to the impact of a particular clue to a search outcome is sometimes difficult to assess first hand and more so from reading search records. Sensitivity testing was performed using double this frequency, 20%.

Some MPs re-appear regardless of the search effort.

Some MPs find their own way to safety regardless of the search. More would do so if a search were not conducted. The relative efficiency of different search methods in some cases will affect the experiences of these MPs. Additionally, this will impact search statistics as a fast method might find an MP who, given more time, would have self-recovered. However, the choice of methods results in no significant difference to the fate of these MPs. For the modelling in this study, the 100 hypothetical MPs are assumed to be MPs who would never have self-recovered.

Combining Search Methods

The model enabled assessment of two important real-life factors that add overarching complexity. At this stage the model has assumed that:

- any technique that lies between Voice and Line in its emphasis has a POS somewhere in between.
- only one search method is used for the duration of the search.

To address the more complicated reality, the model assessed the POS of a search strategy that employs Feature Searching (a method that lies somewhere between the extremes of Line/Grid and Voice) in conjunction with Line Searching. The hypothetical search unfolds in the following way:

Day1 100% of skilled off-track searchers all employed by Feature Searching.

Lack of success creates concern that the MP is unresponsive close in and possibly alive. Therefore...

Day2 25% of those searchers are redeployed in some form of Line Searching close to LKP while 75% continue Feature Searching.

Concerns deepen, resulting in...

Day3 50%/50%
Day4 75%/25%

This pattern is intended to represent an unfolding of events, rather than a predetermined strategy but for simplicity will be referred to from this point on as the Base Strategy.

The Calculations

Using MS Excel, the following processes were performed.

Step 1

The 100 MPs were assigned to each of the four segments according to the opening POAs.

Applying the assumptions in Table 3, the model predicted the proportion of MPs who would be expected to be Responsive, Unresponsive Alive and Deceased at SOD1 within each segment.

Starting with the Base Case assumptions, the model calculated how much area can be searched in Day 1 using the assumptions in Table 1 if the workforce is employed entirely in Feature Searching. The model assigned the searching in the segment of highest PDEN of responsive MPs (Segment 1), continuing in Segment 2 if Segment 1 was completed within the day.

The model then calculated how many MPs in each condition would be found in each segment or sub-segment searched, and therefore how many MPs of each condition remain in each segment or sub-segment. The model recognises that some of these MPs would be found directly and some via clues. A separate tally of clues found and remaining was kept for each segment or sub-segment.

For the workforce deployed in this way, the numbers of MPs remaining in each condition in each segment were adjusted to factor in the drift of some surviving MPs onto ground already searched.

The numbers of MPs in each condition in each segment or sub-segment were then adjusted to reflect deterioration from one condition to the next in proportions dictated by calculations derived from Table 3.

Using these revised populations and the workforce allocation of Day 2 of the Base Strategy, all of these processes were repeated for Day 2. Only 75% of the workforce was assigned to Feature Searching which they continued in the segment or subsegment which offered the highest POS for that method that day. 25% of the workforce started Line Searching for the remaining MPs and clues in the already searched Segment 1.

For Day3 and Day 4, the model repeated the process, using a workforce split of 50/50 and 25/75. The Feature Searching was applied always to the segment or subsegment with the highest POS for Feature Searching and the Line Searching always continued in the areas of highest PDEN for survivors in the areas previously feature searched.

The POSs as at each SOD (assuming that the MP has not been found) could then be calculated for the Base Strategy.

POS_{sav} as at SOD1 = sum(MPs found alive Days 1,2,3,4)/100

In Table 6, this is the top left figure. The figure below it is

POS_{sav} as at SOD2 = sum(MPs found alive Days 2,3,4)/(100 – MPs found Day 1)

Likewise, POS_{sav} as at SOD3 = sum(MPs found alive Days 3,4)/(100 – MPs found Days 1,2), and

POS_{sav} as at SOD4 = sum(MPs found alive Days 4)/(100 – MPs found Days 1,2,3)

POS_{fin}s were calculated by substituting MPs found alive with MPs found alive or deceased.

The process was repeated for

- the Base Strategy but using Voice Searching instead of Feature Searching (Strategy 2)
- 100% Feature Searching only (Strategy 3)
- 100% Voice Searching only (Strategy 4)
- 100% Line Searching only (Strategy 5 (Line alone))
- Line as employed after Voice or Feature Searching. (Strategy 5 (Line following))

Step 2

The POSs calculated for SOD2, 3 and 4 thus far are based on different starting points and so do not provide valid comparisons because the most effective methods find and remove more MPs in the first day and so have less MPs to seek thereafter. To make valid comparisons for the later SODs, the model compared the POSs as at SOD2 for each alternative strategy if departing from the Base Strategy only at SOD2. It did the same for SOD3 and SOD4. For example, at SOD3: the search so far has been 100% Feature Searching on Day 1 and 25% Line / 75% Feature on Day 2; the model then compares going to 50% Line / 50% Feature for Day3 and so on as per the Base Strategy, as against:

- 50% Line / 50% Voice and so on, or
- 100% Feature thereafter, or
- 100% Voice thereafter, or
- 100% Line thereafter.

(Table 7)

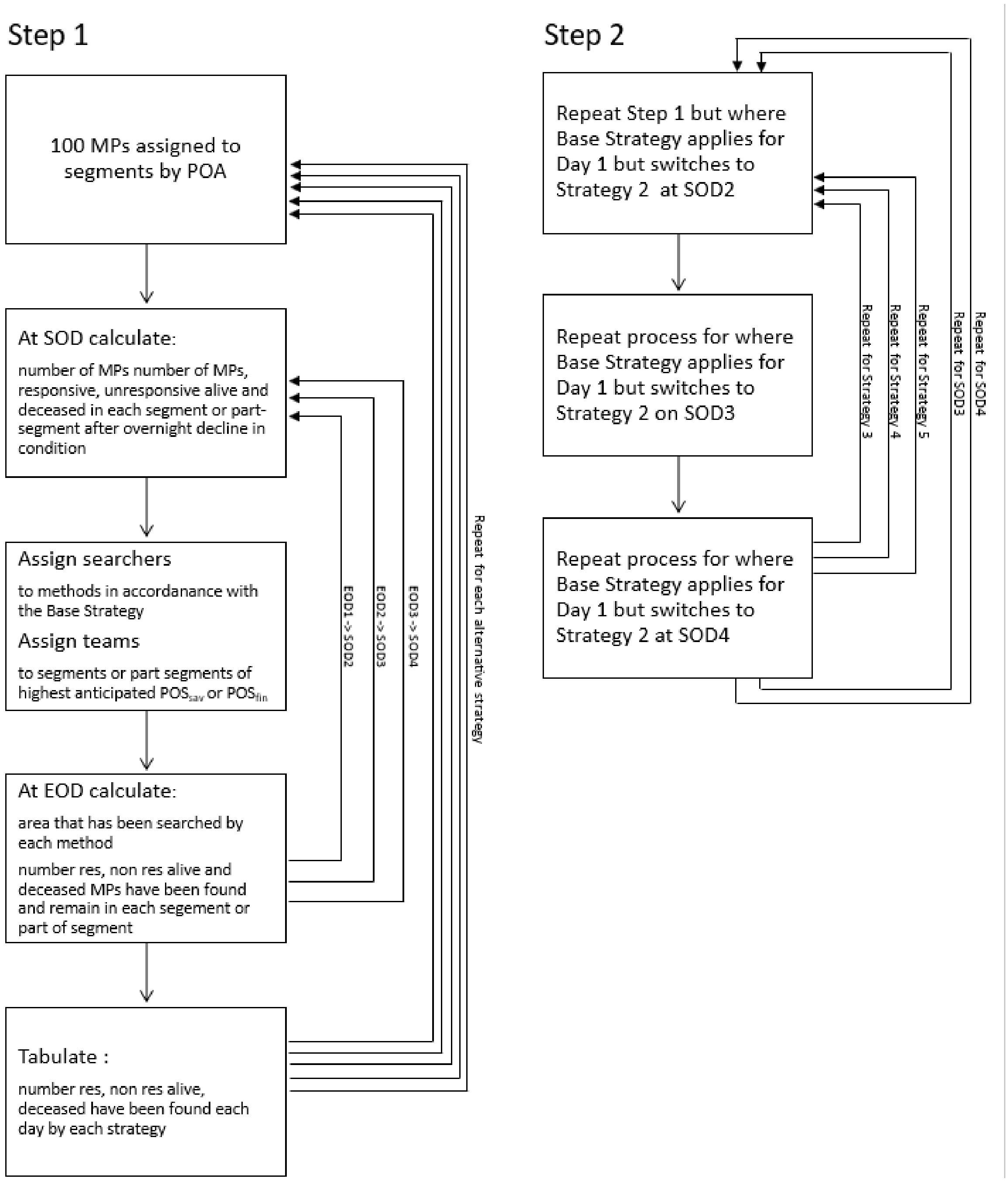
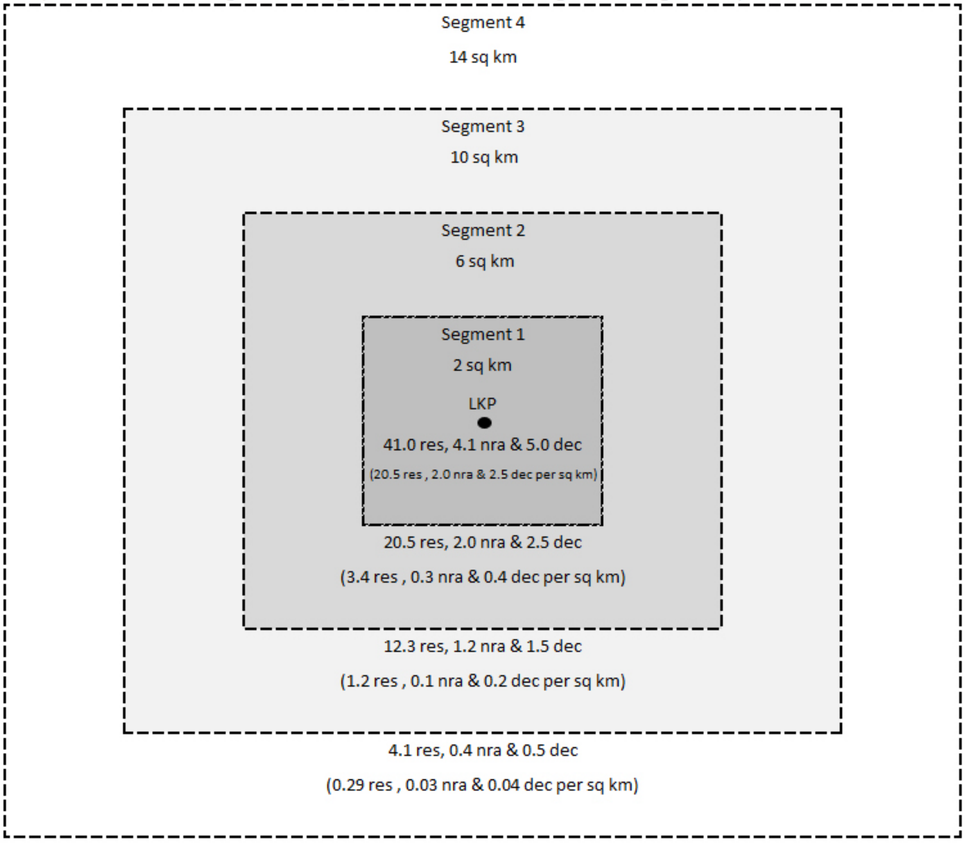

Step 1
100 MPs assigned to segments by POA
At SOD calculate:
number of MPs number of MPs, responsive, unresponsive alive and deceased in each segment or part-segment after overnight decline in condition
Assign searchers
to methods in accordanance with the Base Strategy
Assign teams
to segments or part segments of highest anticipated POS_sav or POS_fin
At EOD calculate:
area that has been searched by each method
number res, non res alive and deceased MPs have been found and remain in each segement or part of segment
Tabulate :
number res, non res alive, deceased have been found each day by each strategy
EOD1->SOD2
EOD2->SOD3
EOD3->SOD4
Repeat for each alternative strategy
Step 2
Repeat Step 1 but where Base Strategy applies for Day 1 but switches to Strategy 2 at SOD2
Repeat process for where Base Strategy applies for Day 1 but switches to Strategy 2 on SOD3
Repeat process for where Base Strategy applies for Day 1 but switches to Strategy 2 at SOD4
Repeat for Strategy 3
Repeat for Strategy 4
Repeat for Strategy 5
Repeat for SOD3
Repeat for SOD4

Figure 1 - Calculations

Example SOD Calculations

A representation of the segments arranged as a concentric rectangles, showing status quo at SOD1.


Segment 4
14 sq km
Segment 3
10 sq km
Segment 2
6 sq km
Segment 1
2 sq km
LKP
41.0 res, 4.1 nra & 5.0 dec
(20.5 res , 2.0 nra & 2.5 dec per sq km)
20.5 res, 2.0 nra & 2.5 dec
(3.4 res , 0.3 nra & 0.4 dec per sq km)
12.3 res, 1.2 nra & 1.5 dec
(1.2 res , 0.1 nra & 0.2 dec per sq km)
4.1 res, 0.4 nra & 0.5 dec
(0.29 res , 0.03 nra & 0.04 dec per sq km)

A representation of the segments arranged as a concentric rectangles, showing status quo at SOD3

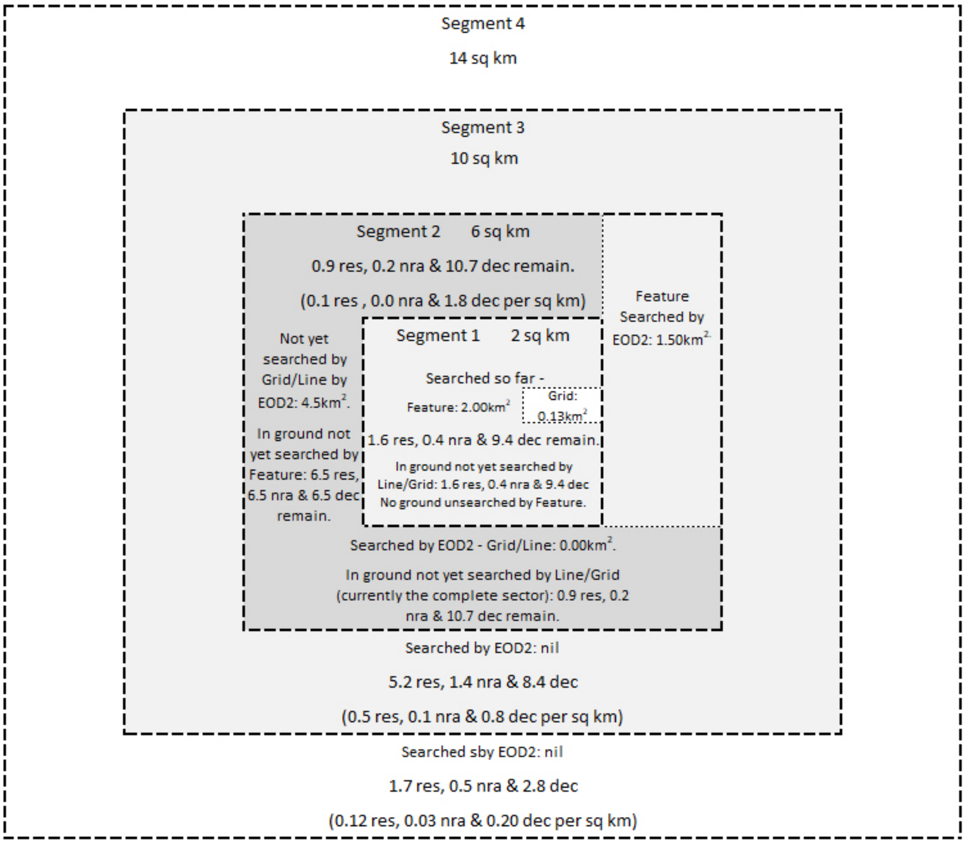

Segment 4
14 sq km
Segment 3
10 sq km
Segment 2 6 sq km
0.9 res, 0.2 nra & 10.7 dec remain.
(0.1 res , 0.0 nra & 1.8 dec per sq km)
Feature Searched by EOD2: 1.50km^2.
Not yet searched by Grid/Line by EOD2: 4.5km^2.
In ground not yet searched by Feature: 6.5 res, 6.5 nra & 6.5 dec remain.
Segment 1 2 sq km
Searched so far -
Feature: 2.00km^2
Grid: 0.13km^2
1.6 res, 0.4 nra & 9.4 dec remain.
In ground not yet searched by Line/Grid: 1.6 res, 0.4 nra & 9.4 dec
No ground unsearched by Feature.
Searched by EOD2 - Grid/Line: 0.00km^2.
In ground not yet searched by Line/Grid (currently the complete sector): 0.9 res, 0.2 nra & 10.7 dec remain.
Searched by EOD2: nil
5.2 res, 1.4 nra & 8.4 dec
(0.5 res, 0.1 nra & 0.8 dec per sq km)
Searched sby EOD2: nil
1.7 res, 0.5 nra & 2.8 dec
(0.12 res, 0.03 nra & 0.20 dec per sq km)

Figure 2 - Example SOD Calculations

Finally, because the purpose of the study was to assess the *comparative* value of each alternative at each stage of the search, the POS figures were re-expressed as values *relative* to continuing with the Base Strategy. (Table 8)

Results

Outcomes for 100 MPs

In a search area populated by 100 MPs all of whom fit the MP description and circumstances of disappearance but who are randomly variable all other respects, subject to the Base Case assumptions, the model predicts that the various search strategies will find MPs in the following numbers (Table 5).

MPs Found							
		Base Strategy Day 1 is Feature, but 25% workforce drawn into Line each day	Strategy 2 Base Strategy but with Voice replacing Feature Searching	Strategy 3 Feature Searching only	Strategy 4 Voice Searching only	Strategy 5 Line/Grid Searching (only) (where $POD_{res} \approx 100\%$)	Strategy 5 Line/Grid Searching (following) (where $POD_{res} \approx 0\%$)
Found Alive	Day 1	38.2	61.8	38.2	61.8	14.4	3.5
	Day 2	3.0	4.4	3.8	5.9	9.2	2.8
	Day 3	1.3	1.6	2.1	1.4	5.9	2.1
	Day 4	0.6	0.2	1.1	0.5	2.4	1.1
	Total	43.2	68.0	45.2	69.5	31.8	9.5
Found Alive or Deceased	Day 1	38.8	62.3	38.8	62.3	16.0	5.1
	Day 2	4.4	5.8	4.2	6.1	14.9	8.5
	Day 3	4.0	4.2	2.6	1.6	14.3	10.5
	Day 4	4.5	3.9	1.7	0.6	9.0	7.7
	Total	51.6	76.2	47.3	70.5	54.1	31.8

Table 5 – MPs expected to be found each day by each strategy.

POS_{sav} is the focus of this study. Figures for Found Alive or Deceased are included to demonstrate that the optimal strategy for resolving the search is not necessarily the optimal strategy for saving the MP.

Conversion to Remaining POS at each SOD

POS at a given SOD is the number of remaining MPs divided by the number of MPs remaining. The SOD1 POSs can be derived directly from Table 5 Totals. The figures for SOD2, 3 and 4 required Table 5 to be recalculated for each SOD (Table 6).

Remaining overall POS							
		Base Strategy Day 1 is Feature, but 25% workforce drawn into Line each day	Strategy 2 Base Case but with Voice replacing Feature Searching	Strategy 3 Feature Searching only	Strategy 4 Voice Searching only	Strategy 5 Line/Grid Searching (only) (where $POD_{res} \approx 100\%$)	Strategy 5 Line/Grid Searching F(following) (where $POD_{res} \approx 0\%$)
POS_{sav}	SOD1	43%	68%	45%	**70%**	32%	**10%**
	SOD2	8%	16%	11%	21%	21%	6%
	SOD3	3%	6%	6%	6%	12%	4%
	SOD4	1%	1%	2%	2%	4%	1%
POS_{fin}	SOD1	52%	76%	47%	71%	54%	32%
	SOD2	21%	37%	14%	22%	45%	28%
	SOD3	15%	25%	8%	7%	34%	21%
	SOD4	9%	14%	3%	2%	16%	10%

Table 6 – POS of each strategy, including POS remaining each day if search is not yet successful.

POS when switching to an alternative strategy on a later day

This paper began with a simple calculation that suggested that Voice Searching is 60 times more effective than Line/Grid searching for MPs who meet the premise (by nature can hear, can call, want to be found). By factoring in uneven PDEN, declining MP condition, clues and mobility, the model calculated the factor to be approximately 7, assuming the Base Case assumptions and that Line/Grid searching never precedes some form of searching by sound. This ratio is derived from the bolded figures in Table 6.

Taking the Base Strategy as the default, the model then calculated the POS of the remainder of the search as at each SOD if the strategy were to be switched at that SOD from the Base Strategy to one of the alternatives. SOD1 results (using the alternative strategy from the very start) are included for completeness. (Table 7).

		Remaining POS if search switches from Base Strategy to..				
		Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 5
	If considering a change of strategy from Base Strategy at	Base Case but with Voice instead of Feature Searching	Feature Searching only	Voice Searching only	Line/Grid Searching (only) (where POD_{res} ≈ 100%)	Line/Grid Searching (following) (where POD_{res} ≈ 0%)
POS_{sav}	SOD1	68%	45%	70%*	32%	10%
	SOD2	25%	11%	29%	5%	3%
	SOD3	10%	6%	15%**	3%	2%
	SOD4	3%	2%	6%	1%	1%
POS_{fin}	SOD1	76%	47%	71%	54%	32%
	SOD2	38%	14%	30%	28%	26%
	SOD3	22%	8%	17%	20%	19%
	SOD4	11%	3%	8%	11%	10%

Table 7 – POS of switching from the Base Strategy to alternative strategies at each SOD

Using the asterisked (*) figure as an example, if Voice Searching is used exclusively from the start of searching, this figure will be the starting POS_{sav} of searching by voice for as long as it takes, up to a limit of 4 days. Using the double asterisked (**) figure as an example, if the search unfolds as per the Base Strategy for Days 1 and 2, this will be the POS_{sav} of searching by voice from SOD3 to the end of Day 4.

Comparing POS of alternatives with Base Strategy

The model then *compared* the POSs of switching on any day to one of the alternatives, as against continuing with the Base Strategy. The results are displayed in Table 8.

		Comparison with Base Strategy at each Start of Day				
		Strategy 2	Strategy 3	**Strategy 4**	Strategy 5	Strategy 5
	If considering a change of strategy at.	Voice & Line : Base Strategy	Feature only : Base Strategy	**Voice only : Base Strategy**	Line/Grid only : Base Strategy	Line/Grid following : Base Strategy
POS_{sav}	SOD1	1.6 : 1	1.0 : 1	1.6 : 1	0.7 : 1	0.2 : 1
	SOD2	3.0 : 1	1.4 : 1	3.5 : 1	0.6 : 1	0.3 : 1
	SOD3	3.0 : 1	1.7 : 1	4.3 : 1	0.7 : 1	0.5 : 1
	SOD4	2.7 : 1	2.1 : 1	5.8 : 1	0.8 : 1	0.6 : 1
POS_{fin}	SOD1	1.5 : 1	0.9 : 1	1.4 : 1	1.0 : 1	0.6 : 1
	SOD2	1.8 : 1	0.7 : 1	1.5 : 1	1.3 : 1	1.2 : 1
	SOD3	1.5 : 1	0.5 : 1	1.1 : 1	1.3 : 1	1.3 : 1
	SOD4	1.2 : 1	0.4 : 1	0.9 : 1	1.2 : 1	1.2 : 1

Table 8 – The comparative values of switching strategy versus beginning with/continuing with the Base Strategy as at each SOD.

Sensitivity Testing

It is acknowledged that the key assumptions of Base Case are just estimated medians. To test the robustness of the results, sensitivity to significant variations in the assumptions was tested, (Table 9). Sensitivity testing has been conducted for all results. The test results in Table 9 refer to variations in Base case assumptions applied to the comparative value in terms of POS_{sav} of Voice Searching for the duration of the search versus the Base Strategy.

Sources		Sensitivities			
			POS_{sav} ratio at SOD1		
Assumptions	*Source of base assumption*	*Change from base assumption*	*was*	*becomes*	*Significance*
Clues	Speculative	10% -> 20%	1.61 : 1	1.55 : 1	minor
Mobility	Speculative	All factors increased x 2.5	1.61 : 1	1.62 : 1	minor
Time responsive : time alive unresponsive	Speculative	4 -> 2	1.61 : 1	1.60 : 1	minor
Condition decline	Speculative	Daily Survival 70% -> 40%	1.61 : 1	1.61 : 1	minor
Relative speeds of competing methods	Analysis of incident data (Appendices 2 & 3)	Voice : Line 15:1 -> 7.5:1 Voice : Feature 4:1 -> 2:1	1.6: 1	1.3 : 1	sensitive. Suggests a search planner might question the study conclusions if he/she believes Voice Searching at given POD for a responder is no more than about 4 times the speed of Line Searching, to same POD for unresponsive MP, e.g. in noisy weather
Relative PODs	Searcher / author estimates (Appendices 2 & 3)	POD_{res} Feature 90%-> 45% Voice 99% ->45% Line - unchanged	1.6 : 1	1.5 : 1	sensitive. But not sufficient to cast doubt on the study conclusions. This also roughly equates to an MP being 50% responsive by nature.
Workforce v Land Area	Arbitrary	8 teams -> 4 teams (which is also equivalent to doubling the search area)	1.6 : 1	2.0 : 1	Sensitive. But simply reflects that the effect loses significance if the workforce is large enough to search the entire area in a single day.

Distribution of PDEN	Arbitrary	Bullseye -> uniform PDEN	1.6 : 1	5.5 : 1	v sensitive. But indicates that the study conclusions will be understated in relation to a very large search area
	Koester, 2008	Bullseye -> LPB Hiker*	1.6 : 1	2.0 : 1	sensitive. But not sufficient to cast doubt on the study conclusions
	Arbitrary	Bullseye -> Intense bullseye	1.6 : 1	1.4 : 1	sensitive. But not sufficient to cast doubt on the study conclusions

**The distribution of MPs when found, from* Lost Person Behavior*, (Koester, 2008), data for Hikers.*

Table 9 – Sources of Base Case Assumptions and Sensitivity of Results to Assumptions

Discussion

Interpretation of results

By comparing strategies, Table 8 demonstrates that:

- searching by voice offers a strong advantage over searching by sight and over any method or strategy combining voice and sound in any search matching the premise (MP is responsive by nature, wants to be found).
- that, if saving life remains the objective, the case for searching by voice does not diminish with the passage of time, notwithstanding the diminishing probability of responsiveness.
- other strategy comparisons differ significantly depending on the objectives of the search (finding versus saving), demonstrating a broader principle that optimising POS depends on specifying the objective.

It follows that searching by voice should be the favoured method for all searchers who are capable of executing such a method systematically. However, there may be strong and well-defined reasons to do otherwise.

Limits of application

If there is a very clear reason to favour searching by sight, this study's conclusions might not hold.
Exceptions include:

Not Meeting the Premise

It is acknowledged that the findings are limited to searches which are predicated on the MP being by nature responsive to some degree.

Workforce expertise

The study assumes that there is a workforce capable of being deployed searching by voice in a safe and accountable way.

Clues near LKP

Common sense would suggest that the value of searching for clues in the immediate vicinity of LKP can outweigh the value of searching by sound. The model is not sufficiently fine-grained to indicate whether the potential value of searching specifically for clues in the immediate vicinity of LKP outweighs the value of searching by sound.

Reaching the limits of the search area

A limitation unstated earlier in this paper is that occasionally, it might be possible to search by voice to ~100% POD to the limits of the Search Area and must therefore cease.

Exceptions do *not* include that the MP will likely have been rendered unresponsive by the duration of their ordeal.

Robustness of results

The conclusions of the study are open to question to the extent that its numerical assumptions are speculative or are likely to be dependent on a search situation. To test the robustness of the conclusion that Voice Searching is superior to Line and intermediate methods, sensitivity tests were conducted.

In each case, a single assumption or a group of related assumptions was changed to test the impact that the imprecision of the Base Case assumptions has on the study conclusions. (Table 9)

The sensitivity tests indicate that the study's broad conclusions are robust, despite the relative lack of data to support the numerical assumptions.

There is some sensitivity to the key assumptions related to relative speeds of search methods. However, only if the observations presented in Appendices 2 & 3 were extremely unrepresentative of average search experiences would that sensitivity cast doubt on the study conclusions.

Objectives of the search

There are two issues relating to search objectives on which the reviewed literature is silent.

- That selecting optimal search methods and strategy can depend on whether the objective is to save the MP or to resolve the search as soon as possible without regard to the MP's possible condition.
- How to decide when the saving objective should be abandoned, given that the MP's survival prospects will never be absolutely zero.

The apparent absence of LandSAR wide protocols means that this modelling cannot predict when in the hypothetical search the objective should change. Hence the numerical results have been presented as two parallel tables (POS_{sav} and POS_{fin}), rather than measuring an overall POS.

Although it was not the focus of the study, it is worth noting that the importance of making POS_{sav} the exclusive objective of a search while survival remains in prospect is demonstrated by the results tables.

Definition of responsiveness

The definition used in this study is not the usual medical definition because, for the purposes of searching, merely being able to whisper is of no aid to a searcher. Its imprecision is acknowledged, but the sensitivity of results to this imprecision can be estimated from Table 9. For example, if the MP by nature has about half the average carry of a person's voice, this would roughly equate to halving the speed of Voice Searching.

Degrees of responsiveness

The findings suppose that every MP is completely responsive at time of disappearance. That is, if the MP hears a searcher, they will reliably reply.

Therefore, if the MP is known to be by nature unresponsive, Voice Searching or any other sound-based method becomes ineffective. But the reality will often be less clear. If an intellectually impaired MP, is described as "unresponsive", that might mean something less than completely unresponsive. A person known to be depressed might be suspected of being in the wilds to commit suicide and therefore not motivated to respond but might be simply lost. Voice Searching becomes marginal where the probability of innate responsiveness falls below a certain point. Further investigation is needed, but at this stage, a rough exploration of this question indicates that the crossover is of the order of 30%. That is, on average, if the MP is thought to be by nature more than about 30% likely to be responsive at time of disappearance and all searchers are considered capable of searching by voice, Voice Searching should be the priority.

Expert medical advice

The study employs an abstract assessment of the relative probabilities of responsiveness, living unresponsiveness and death. The underlying supposition is that for want of better knowledge, the search planner can only assume a general pattern of decline. In reality, most search planners will have access to expert medical advice based on the particulars of the individual, the weather and the terrain. It would be natural to assume that when that advice indicates that the most probable timeline of decline of the MP in question would put that MP in the alive/unresponsive state, searching should focus on the immobile unresponsive MP. However, Voice Searching will normally continue to offer the highest probability of saving the MPs life. That is because the probability of the MP being responsive will still be significant, even if small, compared to the probability of the MP being alive/unresponsive. Suppose for example that the probabilities at that point are P_{res} 20%, $P_{alive\ non}$ 60%, P_{dec}: 20%, the relative effectiveness of sound over sight overwhelms those odds.

Other search methods

There are other sound based methods in use around the world. Many involve whistles. Any sound based method that can be shown to be more effective than the Voice Searching method considered in this study, will provide an even greater advantage over Line/Grid Searching or intermediate methods.

Approximations to search theory

Search literature contains many references to repeat low POD searching and some readers might question the use of 100% target PODs in this analysis.

The advantage of repeat low POD searching is that the first sweep is more efficient in terms of POD per searcher. While it is possible to justify this with mathematical theory, it is more simply viewed as improving productivity by reducing the overlap between each searcher. While each repeat sweep will then have a progressively lower POD given the growing *im*probability that the MP is there, the repeat sweeps can eventually achieve a high cumulative POD. Because the MP has a limited life expectancy, there is advantage is in the timing.

The model has the capacity to examine repeat low POD searching, if the PDEN calculations justify repetition. But this adds considerable and unnecessary complexity to comparisons. Exactly at what target POD that approach is optimised is a complex matter, requiring an algorithm that balances the pure mathematical advantage of separating searchers or search teams almost infinitely versus the logistical cost of increasing separation and the unpredictable degree to which searcher paths on any repeat sweep will be independent of any previous sweep paths.

A target POD often suggested is approximately 60%, as if perhaps to suggest that the balance between mathematical theory and practical considerations is optimised at that POD, or perhaps in reference to the unrelated POD within one Effective Search Width as defined by Koopman, 1946. If all methods used in this study were to have their PODs equally reduced to 60%, the comparison of search methods would change slightly because of MP mobility issues, but the change in POS comparisons, and therefore conclusions, would be slight.

Further, to keep complexity manageable, the model takes a simplified approach to the concepts of POD, ignoring the concepts of Cover and Effective Search Width. The author believes this approach is sufficiently accurate for the purpose.

Limitations of the study

The nature of modelling

A model must always approximate the complexities of real life. There is almost limitless scope to include minor influences and to refine calculations. But it is always necessary to limit refinements to those that have a prospect of significantly impacting outcomes.

The conclusions of this study are simple and broad and so it is the author’s opinion that all factors of a magnitude that will impact on the findings have been considered.

Benchmarking of inputs

The relative speed of search methods is a critical assumption. Objective observations require different methods to have been used by similar teams in very similar terrain and weather conditions, preferably without the searchers knowing that their speed will be measured. This happens on a real-life search only by rare chance. A mock search for the purpose would be difficult to construct and would be beyond the resources of this study. The incident analysed in Appendix 2 was one such rare real-life occurrence and was the inspiration for this study. The incident analysed in Appendix 3 is the only example available to the author that is close to providing a direct comparison of Line/Grid with Voice. More data might come to hand with the passing of time.

Estimating instantaneous POD

The POD’s used in the Base Case are estimates made by the author who was on the ground in three of the four searcher groupings described in Appendices 2 & 3.

The low POD figures are necessarily very subjective and the near 100% figures will invite scepticism. In relation to the latter, it needs to be noted that the near 100% PODs were the target PODs of the tasks and the speeds of operation were the variable, leading to a high confidence in the POD's achieved. Nevertheless, the disputability of the POD's simply highlights that the examples used for Base Case calculations provide just single data points and that this work would be strengthened by more field data.

Future research

Further research into the assumptions

While sensitivity testing suffices for extensive data in this study, it would be affirming to have more data that informs the Base Case assumptions and to understand how much those factors vary between regions: comparative search speeds and PODs; typical timelines of losing condition through losing responsiveness and on to decease; and the statistical impact of clues.

Establishing a base case scenario for further study

Published data does not provide enough information to establish a plausible and defensible base case that reconciles with known statistical outcomes. This and similar studies could be enhanced by further work that establishes all the parameters of a statistically average or median missing person situation and search outcome.

Establishing how innately unresponsive the MP must be before favouring sight based methods

A rough calculation suggests that the study conclusions hold if the MP is thought to have been more than somewhere around 30% likely to respond at time of disappearance. Further modelling should provide a more reliable number for this threshold.

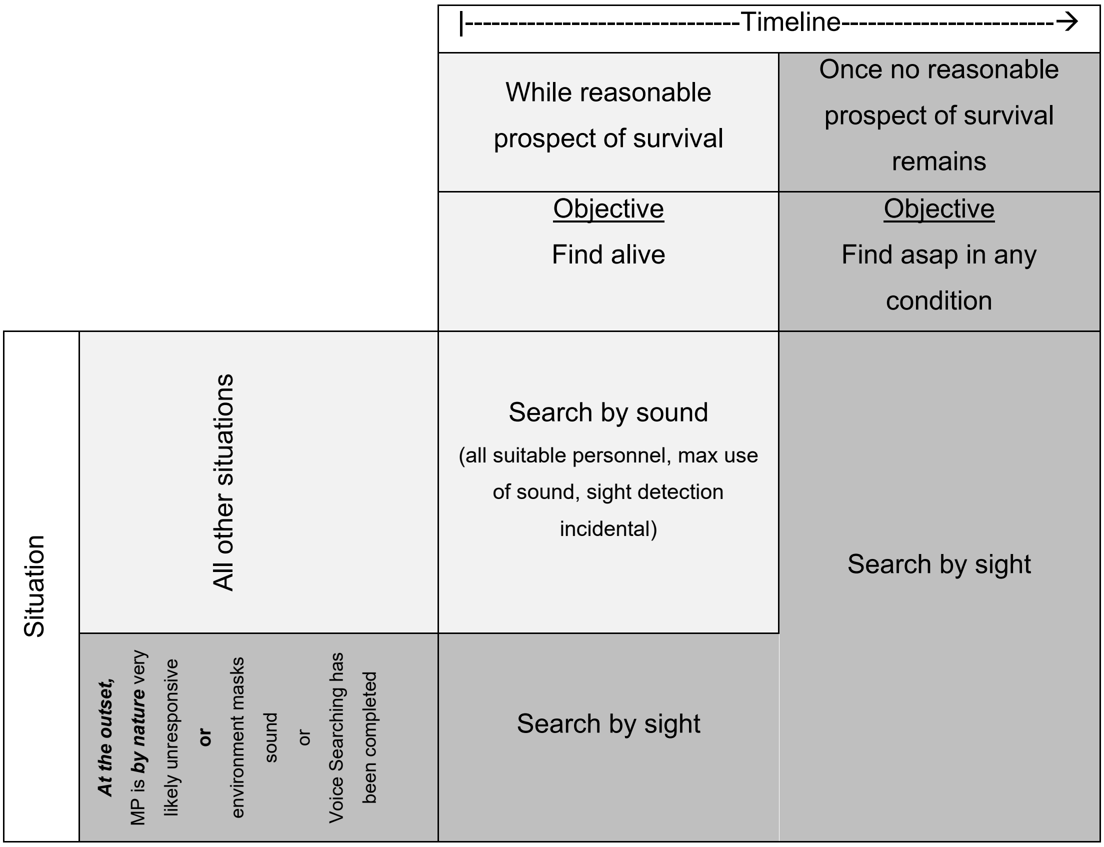
Establishing the approximate limits of the area worth searching off-track by foot

A limitation of these findings is that Voice Searching is of little value once the Search Area has been searched to its realistic limits. Implicitly, those limits will be where the opening PDEN falls below a certain value. This study would be enhanced by further modelling to identify the PDEN that should define the boundaries of the area worth searching.

Conclusions

1. In almost all searches where the MP is by nature capable and willing to respond, notwithstanding their presumed physical decline, off track searching should be conducted with the greatest possible emphasis on detection by sound.
2. While such an MP's survival remains in prospect, tasking skilled searchers to employ methods that assume that the MP has become unresponsive will compromise the probability of saving the MP, even though the MP might still be alive but unresponsive.
3. The model confirms an effect that optimising strategy is dependent on whether the objective of the search at any given time is to save the MP's life or to find the MP alive or deceased as efficiently as possible.
4. While the objective is to save life, the advantage of searching by sound over searching by sight or an intermediate method does not diminish with the passage of time.

Conclusions 1) and 2) are represented diagrammatically in Figure 3.



<table>
<tr><td></td><td></td><td colspan="2">|-----------------------------Timeline------------------------→</td></tr>
<tr><td></td><td></td><td>While reasonable prospect of survival</td><td>Once no reasonable prospect of survival remains</td></tr>
<tr><td></td><td></td><td><u>Objective</u>
Find alive</td><td><u>Objective</u>
Find asap in any condition</td></tr>
<tr><td rowspan="2">Situation</td><td>All other situations</td><td>Search by sound
(all suitable personnel, max use of sound, sight detection incidental)</td><td rowspan="2">Search by sight</td></tr>
<tr><td><b><i>At the outset,</i></b>
MP is <b><i>by nature</i></b> very likely unresponsive
<b>or</b>
environment masks sound
or
Voice Searching has been completed</td><td>Search by sight</td></tr>
</table>

Figure 3 - Decision Matrix

Acknowledgements

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About the author

Rod Costigan has been volunteering for remote area searches in Victoria, Australia, for over 40 years. He has enjoyed a career in banking and finance and business and now guides wilderness expeditions in northern and central Australia. His work in financial derivatives included extensive modelling.

Abbreviations and Terms

Base Case	The hypothetical situation that is used in this study for the purpose of comparing response outcomes.
Base Strategy	A particular combination of Feature Searching and Line Searching, against which other strategies are compared in this study.
EOD	End of Day.
Feature Searching	Searching along gullies or crests, by a combination of sight and calling/listening as described in Appendix 1.
Grid Searching	Several searchers searching by sight in a line approximately perpendicular to the direction of travel. Spacing of individual searchers is fixed.
Line Searching	Several searchers searching by sight in a line approximately perpendicular to the direction of travel. Spacing of individual searchers is fluid and determined by a target POD as described in Appendix 1.
Line/Grid Searching	Line or Grid Searching where for the purpose of this paper the distinction is immaterial.
LKP	Last Known Point – the latest confirmed location of the missing person. For this study, synonymous with Point Last Seen.
MP	Missing Person.
P_{res}	Probability that the MP is responsive at a given point in time.
$P_{alive\ non}$	Probability that the MP is alive but no longer responsive at a given point in time.
P_{dec}	Probability that the MP is deceased at a given point in time.
PDEN	Probability Density – the probability that an object or person (eg an MP or a clue) lies within a defined area, divided by the measure of that area.
POA	Probability of Area – the probability that something (e.g. an MP or object) is within a defined area.
POD	Probability of Detection - the likelihood of locating an object or person.
POD_{res}	Probability of detecting a responsive MP in a completed task by a given method if the MP is in the area searched.
$POD_{non\text{-}res}$	Probability of detecting an unresponsive MP in a completed task by a given method if the MP is in the area searched.
POS	Probability of Success, usually referring to the potential outcome of the entire operation. In this paper, is also applied to each day of operation.
POS_{fin}	Probability of Success, where Success is defined as finding the MP, alive or deceased.
POS_{sav}	Probability of Success, where Success is defined as finding the MP alive (saving).
$POS_{sav(Voice)}$	POS_{sav} of searching entirely by Voice Searching.
$POS_{sav(Line/Grid)}$	POS_{sav} of searching entirely by Line or Grid Searching.
S_{voice}	Speed of Voice Searching.

$S_{line/grid}$	Speed of Line/Grid Searching.
Segment	An arbitrary division of the search area.
SOD	Start of Day.
Sub-segment	Part of a segment, used to refer to the part of a segment that has been searched when the rest has not, or vice-versa.
Voice Searching	Searching with maximum possible emphasis on calling and listening as the means of detection in the manner described in Appendix 1.

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Appendix 1 - Description of Search Methods

The Base Case assumptions speeds and PODs used in this study were based on actual search records (See App 2 & 3). There were three methods in use.

Voice Searching

The term, Voice Searching, has been used here as follows. A team is given a defined area on the map to search to a target 100% for a responding MP. The group, ideally of 2 members, uses each other's voices to judge the carry of voice in the environment and so to space themselves and their contiguous sweeps to ensure that they have travelled and listened to everywhere within the reach of someone calling with moderate vigour (or loader or softer as search control might specify).

Appendix 2 includes the tracks of two searchers who were assigned an area and asked to 'clear' the area for a responding MP. This site lent itself to having the searchers follow features, mostly with one on a spur and the other in the adjacent gully. (Hi-Viz clothing, UHF radios and a meeting point, mitigated any risk of separation). The two searchers were able to consistently assess the carriage of voice by hearing each other and were free to adjust their separation and route to allow for competing sources of sound, e.g. running water, wind. A second task was undertaken but with search planners assigning lines of searching, which were not ideal for this technique - hence a hole in coverage - but which still produces valid data for this study. It is generally supposed that ridgelines and streamlines have a higher PDEN than the spaces between them. Data from Koester, 2008 indicates that about 42% of found Hikers were off track and of these 29% were close to drainage lines. For the purposes of comparing methods, it is important to note that both methods examined in Appendix 2 enjoyed that advantage more or less equally. In executing this task, the Voice searchers interpreted "responding" as being able to call out "with moderate vigour".

The tracks in Appendix 3 are of five searchers, the same individuals who conducted the line search described above. They were separated into two groups (2 and 3 searchers). Each group was assigned one of two contiguous areas to search. Each group was asked to search its area to 100% POD for a responding MP, meaning that they were to report back to their satisfaction that their voices reached every part of their assigned area and that they passed within earshot of any person calling back with "moderate vigour".

Feature Searching

The method referred to in this paper is one where two or more searches follow a line feature, typically following gullies and streams in one direction and returning via spurlines. Suppose that a team of two is following a gully. The searchers will walk either side of the gully at whatever separation ensures a high degree of confidence that the MP is not lying motionless between them. They also scan to the outside of that band. Both searchers will deviate to investigate impediments to line of sight. Both searchers will also be calling and listening, achieving a band of voice coverage of indeterminate with. In some dense gullies, sight POD might fall well below 100% in the interests of time. On the spurs, sight POD might be close to 100% but to a breadth that may be inconsistent or may be to a consistent breadth but an inconsistent POD. This method leaves large gaps in visual coverage between neighbouring sweeps and is open to leaving unrecorded gaps in voice coverage between the features and indeed unnecessary overlap. It can be performed with larger search groups to widen the breadth of the sight searching.

Appendix 2 displays the tracks of three pairs of searchers who had been assigned lines to follow along gullies and adjoining spurs.

Line/Grid Searching

This paper assumes a method of line searching as follows. A team walks in a line roughly perpendicular to the direction of travel. Usually, the searcher at one end follows one boundary of the allocated area, the next searcher spaces him/herself from the first searcher and so walks slightly behind the first. The third works off the position of the second and so on. The last searcher in the line ties maker tape along their path. Each searcher contracts the spacing from the adjoining searcher such that the subject (MP or clue of a specific dimension) is certain to be seen and expands the spacing where sightlines are long. Each searcher deviates momentarily from their line whenever necessary to search where sight lines are broken by occasional fallen wood, ferns, etc. When the far boundary of the tasked area is reached, the line flips around the trailing searcher who then leads by following his/her own tapes.

The term, grid searching, usually applies to the searchers following strictly parallel straight lines. This paper assumes numerically similar outcomes.

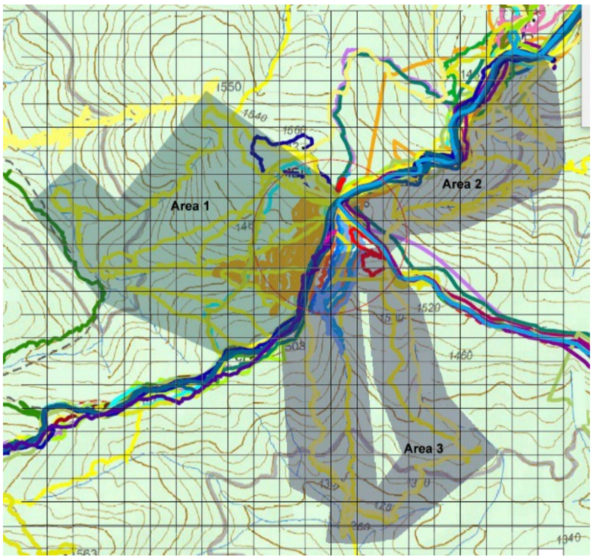
The tracks in Appendix 3 are of a group of five searchers following a broad steep spurline on which there was reason to believe a shoe had been loosely discarded. At slight variance to the above, the leader navigated the central line with two searchers on each side. Searchers at each end taped their paths to facilitate later sweeps as might be required. On each side of the leader, the separation of searchers expanded and contracted as necessary to cover the maximum breadth of ground while ensuring – to the satisfaction of the searchers - 99% POD.

The outcomes have been scaled arbitrarily for an equivalent search for a reclining motionless MP. The factor is an estimate based on an assessment of the vegetation at that location. (The shoe was subsequently found on a different spur.)

Appendix 2
Voice Searching and Feature Searching Strategy Study

Figure A2.1 is a de-identified record from an actual search.

The searcher tracks inside the shading were all recorded on the same day. Area 1 was searched by Teams A, B and C (two members each) who searched using the feature searching routine described in Appendix 1.Area 2 and 3 were searched by Team D who switched early to the voice searching method described in Appendix 1.



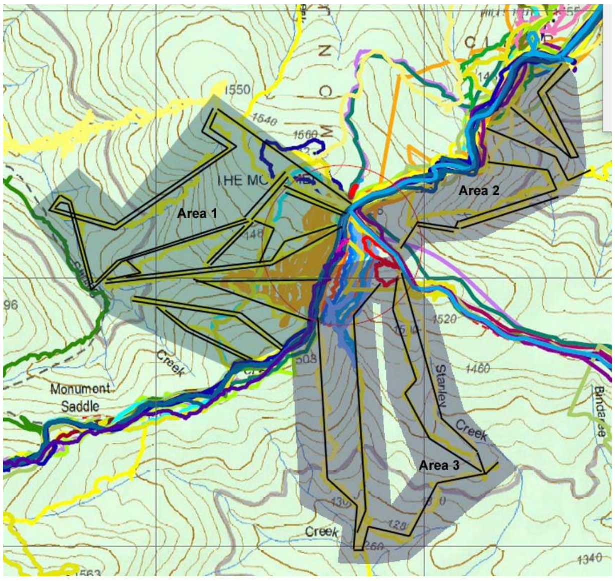
Yellow lines within grey shaded Area 1, measuring ~76 Ha,are of Feature Searching.

Yellow lines within grey shaded Areas 2 & 3, measuring ~96 Ha,are of Voice Searching.

Grey shading represents estimated reach of searching for a responding MP.

(100m grid)

Fig A2.1 - Comparing Land Area searched by Voice Searching and Feature Searching in Comparable Terrain



Yellow lines within grey shaded Area 1are of Feature Searching.

Yellow lines within grey shaded Areas 2 & 3 are of Voice Searching.

Black lines represent estimated distance walked over. Two searchers one behind the other is a single line.

(1000m grid)

Fig A2.2 - Comparing Distanced Walked by Voice Searching and Feature Searching in Comparable Terrain.

		Teams A, B and C collectively Area 1 (Feature Searching)	*Team D Total of Areas 2 & 3 (Voice Searching)*	*Relative speed*	*POD for area searched (Responding MP)*	*POD for area searched (Unresponsive MP)*
From Figure A2.1	*Approximate area searched **by voice***	76 Ha	96 Ha		**100%**, but acknowledging that the MP could enter the area after searching.	unknown
	Per searcher	12.3 Ha	48 Ha	12.3/48 =**0.26** **(or 3.9)**		
From Figure A2.2	*Approximate area searched **by sight** (assume10m band pp)*	10.6km x 10m = 10.6 Ha	7.5km x 10m = 7.5Ha		**unknown** Possibly 100% because of the close search tasking, but actually unknown.	unknown
	Per searcher	1.8 Ha	3.8Ha	1.8/3.8 =**0.47 (or 2.1)** but acknowledging that the approximating factors that the voice searchers were not as thorough with sight searching but that their effective width was not reduced by overlap.		

Table A2.1 - Calculating Relative Speeds of Feature Searching and Voice Searching

This rough comparison suggests:

- that the team searching by **voice** for a **responding MP** searched about **four times** the area per searcher than the teams searching for a responding MP by Feature Searching and with the advantage of a quantifiable outcome
- that, surprisingly, the probability per searcher of finding an **unresponsive MP by sight** was **~2.1 x greater for the voice searchers** than the feature searchers.

Approximately comparable PDENs have been assumed.

Appendix 3

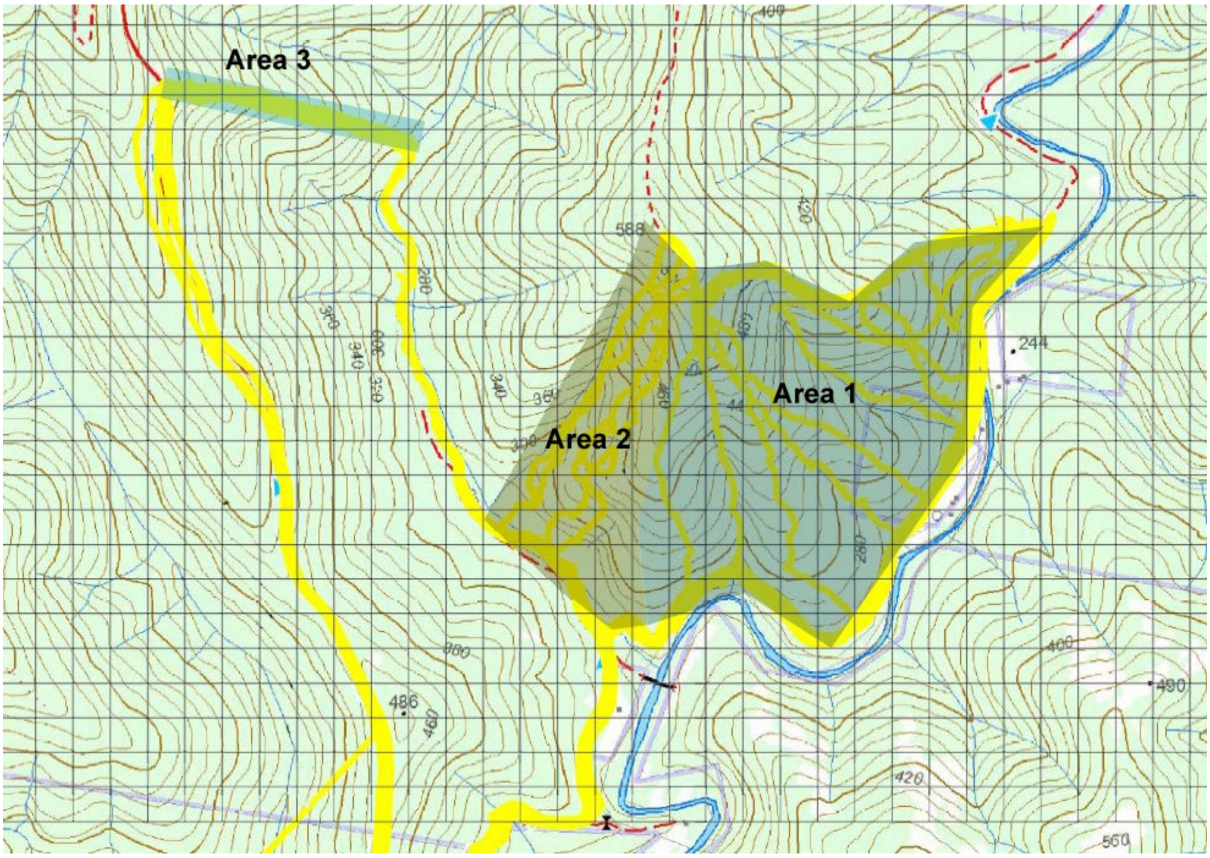
Voice Searching and Line Searching Strategy Study

Figure A3.1 is a de-identified record from another actual search.

Table A3.1 uses tracks were recorded by the same group of five searchers on the same day in almost identical terrain, all downhill.

Area 1 was done by a team of two as a voice search. Simultaneously, Area 2 was searched by a team of three.

Later the two teams combined to perform a line search of Area 3. This was a search for a brightly coloured shoe that there was reason to believe that MP might have discarded on this spur line. In Table A3.1, an estimation has been made by one of the searchers (the author) of the breadth that the team would have searched to the same thoroughness and speed if the subject had been an immobile unresponsive person.



(100m grid)

Yellow lines within grey shaded Areas 1 & 2 are of Voice Searching.

Grey shading of Areas 1 & 2, measuring ~110 Ha, represents estimated reach of searching for a responding MP.

Yellow lines within grey shaded Area 3 are of Line Searching.

Grey shading of Area 3, measuring ~4.5 Ha, represents estimated reach of searching for an unresponsive MP.

Fig 3.1 - GPS tracks of Voice Searching and Line Searching in Comparable Terrain

		Area 1&2 Voice Searching	*Area 3 Line searching by sight (for blue shoe in mostly clear ground surface, between tightly crowded saplings)*	*Relative speed*
From Figure A3.1	*Approximate area searched*	110Ha	750m x 60m = 4.5Ha	.
	If subject had been unconscious person, extra breadth:		x 2 = 9.0Ha	
	Time taken	1.75 hrs*	2 hrs	
	Ha per searcher per hour	12.6 Ha / p / hr	0.9 Ha / p / hr	**14:1**
	PoD for area searched (Responding MP)	**100%**, but acknowledging that the MP could enter the area after searching	**~98%**	

Table A3.1 - Calculating Relative Speeds of Line Searching and Voice Searching

This rough comparison suggests:

- that the team searching by **voice** for a **responding MP** can search about **fourteen times** the area per searcher per hour for the responding MP than a line search for an **unresponsive MP** in that particular terrain.

Quick Release Harnesses; Loads on a High Line

Simon Allfree*
Canolfan Tryweryn The national Whitewater Centre, Frongoch, Bala, Gwynedd LL23 7NU

Loel Collins
Moray House School of Education and Sport, University of Edinburgh, Edinburgh, Scotland

Chris Onions
Canolfan Tryweryn The national Whitewater Centre, Frongoch, Bala, Gwynedd LL23 7NU

Abstract

This study examines the loads associated with positioning a Rescuer on a Quick Release Harness (QRH) on a high line in moving water. Testing was conducted at water speeds of 0.6 - 2.4m/s, typical of those encountered during water related rescues. A Rescue Randy Combat Challenge Manikin (65kg) was positioned on a QRH from a high line and an in-line load cell utilised to collect force/time data. The findings identify operational water speeds for positioning Rescuers in water using a QRH. The study contributes to the work by Onions and Collins in their earlier investigations and the understanding the loads placed on high lines during rescues by the emergency services.

Key Words: Quick Release Harness, swift-water rescue, water rescue

Introduction

Positioning as Rescuer in fast flowing water to execute a rescue is frequently both risky and time pressured. Typically, given resource and time, a suitable craft is deployed. However, a quicker but risker option exists, that of using a rescuer via a quick release harness (QRH). The use of a QRH is significantly riskier and requires the response team to be highly skilled, experienced and practiced. Consequently, we see such approaches used more readily in small teams of recreational kayakers and canoeists and highly specialised, experienced and skilled first responders.

Onions and Collins (2017) reported on the loads generated by rafts on a highline and highlighted the need for Rescuers to understand the performance of the raft being lowered from that highline (Onions & Collins, 2017). Bechdel and Ray (1997) suggests that 'any watercraft can be used for the lower' (p126.). Indeed, commercial rafts in a range of sizes, rafted canoes, semi ridged dory's both flat bottomed and rigid 'v' shaped hulled and Rescuers utilising quick release chest harness have all been proposed (Bechdal & Ray, 1997; Ferrero, 2006). This paper reports on the second of three related studies utilising a variety of techniques to position a Rescuer. This report is in effect drawing together Onions (2012); Onions and Collins, (2013), Collins and Onions, (2014); Onions and Collins, (2017). to expand understanding and inform better decision-making during emergency responses.

The aim of this work to advance the understanding of the loads generated and the practicality of a Rescuer using a QRH deployed from a highline, to consider whether quick release harness applications generate similar patterns of load to rafts when deployed from a highline and then discuss the implications for the responder.

Literature Review

Positioning a Rescuer in the flow using a QRH to retrieve a casualty or equipment is a recognised technique in swift water rescue. It is often used if the rescue is time critical, access is problematic or suitable watercraft are not readily available.

Personal Flotation Device (PFD)

A PFD is a vest or jacket suitable for water rescue, consisting of shaped, closed-cell foam sections positioned against the wearer's torso. PFD's enable the wearer to swim in a conventional facedown (front-crawl position) that would otherwise be impossible in a life jacket. The PFD also has some degree of impact protection around the torso and facilitates defensive swimming in swift water. A typical life jackets does not facilitate conventional / aggressive swimming and does not protect the spine of the user. In addition to the buoyancy of the jacket, there is typically also a webbing structure around the outside of the buoyant material that performs multiple functions including the stowage of safety equipment (knives, whistles, prusik loops, etc.). The webbing also introduces a structure and form to the PFD during a rescue, although the details of design vary between manufactures. In addition to these generic features, rescue PFD's also consist of QRH that provides an anchor point for a throw line (tethering line) via a dorsal attachment point.

Tethered Swim Rescues

The most frequent swift water rescue application for a Rescuer using a QRH is to enter the water with a throwline attached to the dorsal point of the harness, while being belayed from the shore (Figure 1), make direct contact with the casualty and then allow the flowing water to wash both parties back to the Rescuers' bank (Rescue 3 International 2018). Authors have variously described these methods as live bait (Ferrero, 2006) or tethered swim rescues (Rescue 3 International 2018). These are considered high risk rescues, however in small, experienced response teams are quick/ snatch rescue responses that generate momentary loads on Rescuer, belayer and casualty as they are recovered. They are most frequently employed as down-stream safety in rescues.

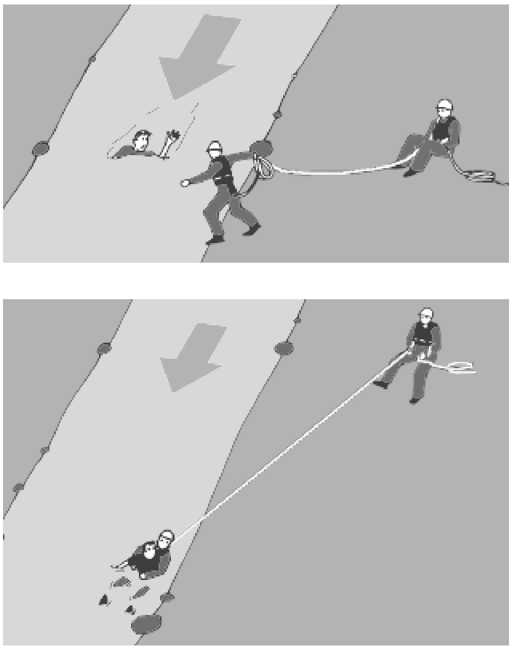


Figure 1: Tethered Swim rescue (Rescue 3 International 2018).

In has been proposed by Ferrero,(2006) and Bechdel and Ray (2009) that a QRH may also have an application in positioning a rescuer to facilitate a rescue.

Positioning Systems

Positioning a Rescuer wearing a QRH in the flow results in sustained loads being experienced by the Rescuer potentially over pro-longer periods. Positioning applications use multiple ropes on opposite banks to position the Rescuer. These systems take different forms; 'V', 'Y' and highline lowers.

V Lowers

The 'V' lower is an adaption of a two-line system used on rafts (Rescue 3 International 2018). 'V' lower systems are generally taught in the swift water context (Rescue 3 International 2018) with two lines attached to the dorsal points of the QRH (Figure 2). Each line is then belayed on either bank of the river. The Rescuer can be positioned by lowering on a single rope (moving the Rescuer both down, away from the releasing side or via lowering via both ropes which results in the Rescuer being lowered downstream (Rescue 3 International 2018).

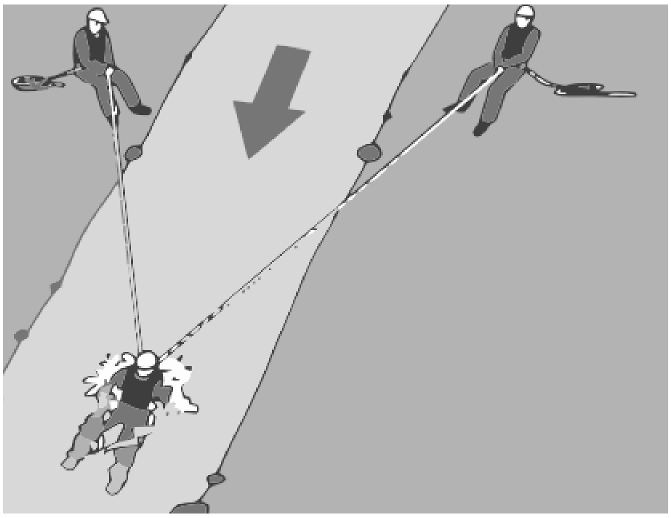


Figure 2: V Lower: (Rescue 3 International 2018).

Y Lowers

The Y lower (Rescue 3 International 2009) is a further adaptation of the two-line system. In this configuration a single line is attached to the dorsal attachment point of the QRH while being belayed to the bank, as in figure1 . A second line is then attached to the first line and belayed from the opposite bank so that a vectored load can be applied to the first, delaying the pendulum effect (Figure 3). The load on the opposite bank belayer is vectored and frequently high. The vector can also be applied actively from the same bank, to speed up the pendulum effect (figure 4). The key advantage of these ‘ Y’ approaches is that it forms a logical evolution from a typical live bait recovery. Allowing anomalies in current vectors and water features to be overcome. These have value in situations that may be at the limit of operation for a Rescuer in a QRH either because of water turbulence, current vectors on bends, complex flows or over coming low river speeds by speeding up recovery.

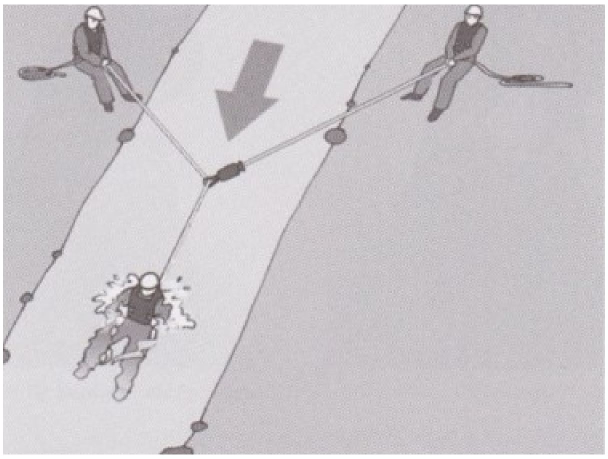


Figure 3: Y Lower, (Rescue 3 International 2009).

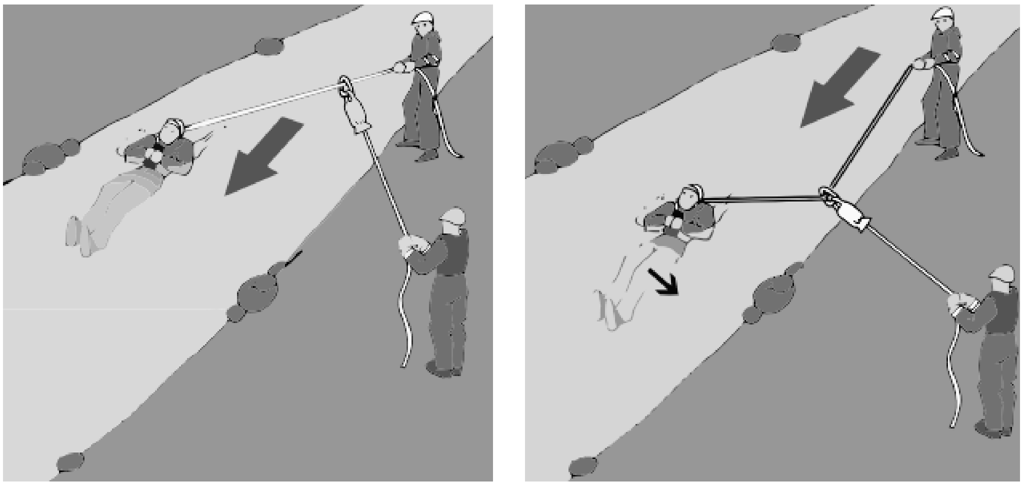


Figure 4: The set up and application of a vector pull to aid a pendulum recovery: (Rescue 3 International 2018).

Both the V and Y lowers are suitable in low river flow velocities that allow lines to be handheld. However, there are clear limitations to these 'handheld' approaches in higher flows as river velocity may exceed the grip threshold of the Rescuers positioned on the bank, or the capacity of the Rescuer in the water to breath duw to pressures acting on the chest. Both Ferrero (2006) and Bechdel and Ray (2009) report the limitation of quick release harness use as being determined by the flow of the water on the user's torso and arms. The loads on the torso having the potential to limit the Rescuers ability to breath and use their arms effectively.

While, load bearing, belays are possible in the V and Y techniques these place demands on equipment and importantly remove an inbuilt load limiting capacity, that of the Rescuers grip. Using direct or in direct mechanical belays consequently can subject the Rescuer in the water to unknown loads. If load holding devices or direct belay techniques are used an understanding of the loads on the Rescuer is required in order to allow safe and effective deployment. The use of load holding devices also brings with it an increased complexity in the rope systems and with it a commensurate increase in risk of entanglement.

Consequently, highline techniques become options if equipment and training allow.

Highline Lowers

Highline techniques vary depending on the force of the water, width of the river and the rope resources available. Commonly used in conjunction with a raft and increasingly with a sled, an application with a QRH represents an improvised solution in formal rescue but remains a ‘last ditch’ option with experienced Rescuers, team of kayakers or canoeists or if a raft or sled are not available. In selecting a QRH application it becomes important to understand the loads generated on a Rescuer.

Method

Building on the work of Onions (2012); Onions and Collins, (2013); Collins and Onions, (2014); Onions and Collins, (2017) concerning a desire for ecologically valid challenges, representative force values needed to be determined in environments in which a Rescuer might be willing to be deployed. The approach of Onions and Collins (2014) was adapted in two ways (1) utilising a more sensitive load cell, addressing the weakness highlighted by Onions, (2013) (2) varying the load on the Rescuers by positioning the rescuer in different positions within a calibrated channel in order to gather different flow rates rather than varying the flow rate by increasing the flow on an artificially pumped channel.

Qualified and experienced Rescue Technicians were used for rigging, assist help with data collection and discuss findings and the implication. Due to the duration required to be in the water a Rescue Randy Combat Challenge Manikin (65kg) dressed and trimmed to float in a defensive swimming position was used. The manakin was equipped in water rescue equipment, river shoes, wet suit, helmet and QRH PFD).

Procedure

Test site

For the purposes of this test a calibrated channel was used 100m downstream of a British standard broad-crested weir (International Standards Organisation, 2008). Flow data was recorded 50cm up stream of the Rescuer before every test to ensure accurate calibration at the site. This was done with a digital flow meter and mean flow calculated at the point of test. The site comprised of gravel beds and earth embankments with some rock armouring at key locations. Due to the nature of the channel the flow type at the test site was turbulent slow flowing being representative of the conditions in which Rescuers on a QRH may be deployed. The approach for determining the force induced by moving water on objects positioned by ropes has been established by Onions (2012); Onions and Collins, 2013; Collins and Onions, 2014; Onions and Collins, (2017). They present the case for capturing data under real world conditions using appropriate equipment in preference to mathematical modelling.

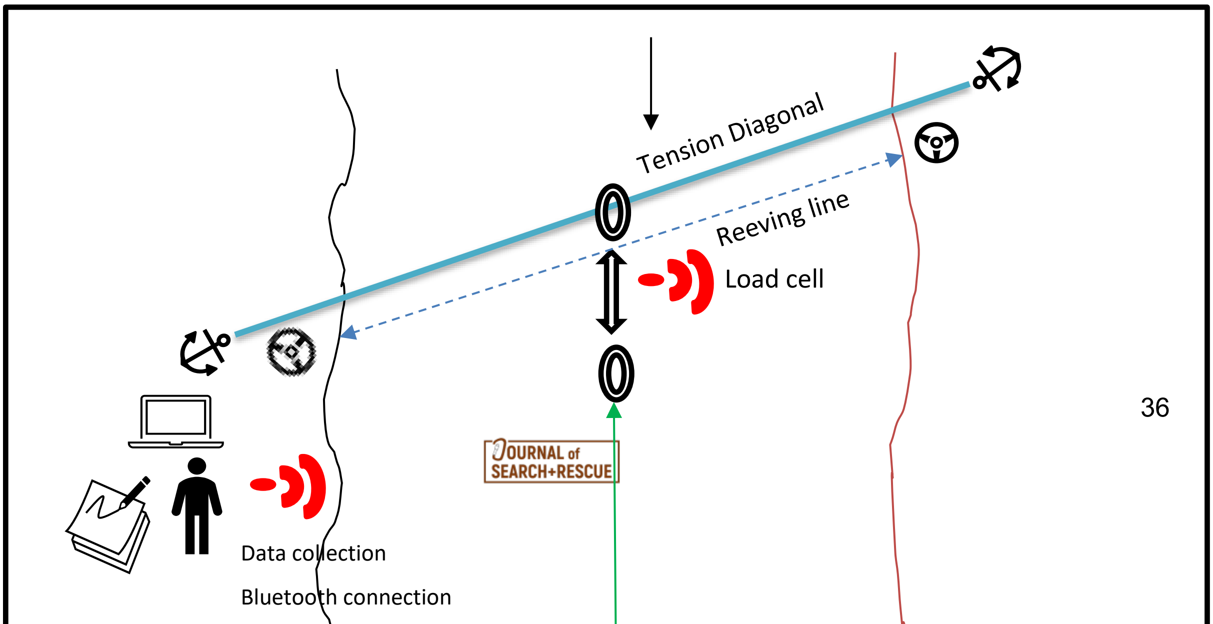
Data Collection

Flow speed data was collected via a Geopacks Advanced Stream Flowmeter and the data transferred into Microsoft Excel via a data cable. Flow speed was measured in meters per second (m/s) to 2 decimal points.

A Bluetooth Rock Exotica Enforcer load cell was connected in series with the tether at the Rescuers up stream attachment to the high line, this recorded the load in kN to 3 decimal places at a rate of 500 samples a second. Data were transmitted via Bluetooth to an iPad and managed using the Enforcer app (version 1.1.1), the data was saved and then transferred to Microsoft Excel. This was then used to produce graphs showing the relationship between mean flow and mean load.

Procedure

A highline system, as a tensioned diagonal was set up as per figure 4. This was rigged in five different locations within the calibrated channel allow the manakin to be positioned in a range of different flow rates. The Rescue Randy Manikin was then moved into positioned and the system allowed to settle for a period of at least one minute. (1) Ten flow velocity readings were then taken 50cm up stream of the manikin allowing a mean flow speed to then be calculated. (2) A minimum of one and a half minutes of force data were then collected at a sample rate of 500 samples/second. (3) The manikin was then repositioned to experience different flow rates in the channel and the procedure repeated. A total of 51 complete data sets were collected over a period of three days.



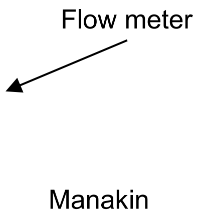


Figure 4: Test set up QRH on a high line. The box on the Rescue Technicians line indicates the position of the Rock Exotica Enforcer load cell. For clarity, the mechanical advantage rigging of the highline and reeving lines have been omitted.

Analysis

The relationship between mean flow in meters per second (X axis / explanatory variable) and the mean load in kilonewtons (Y axis / response variable) was plotted on a graph and regression lines calculated.

Results and Discussion

A strong uphill (positive) linear relationship can clearly be seen in the graph. The R value was calculated as +0.79, indicating 79% of the movement in the response variable can be explained by the explanatory variable tested. This suggets that the results are highly predictive and accurate.

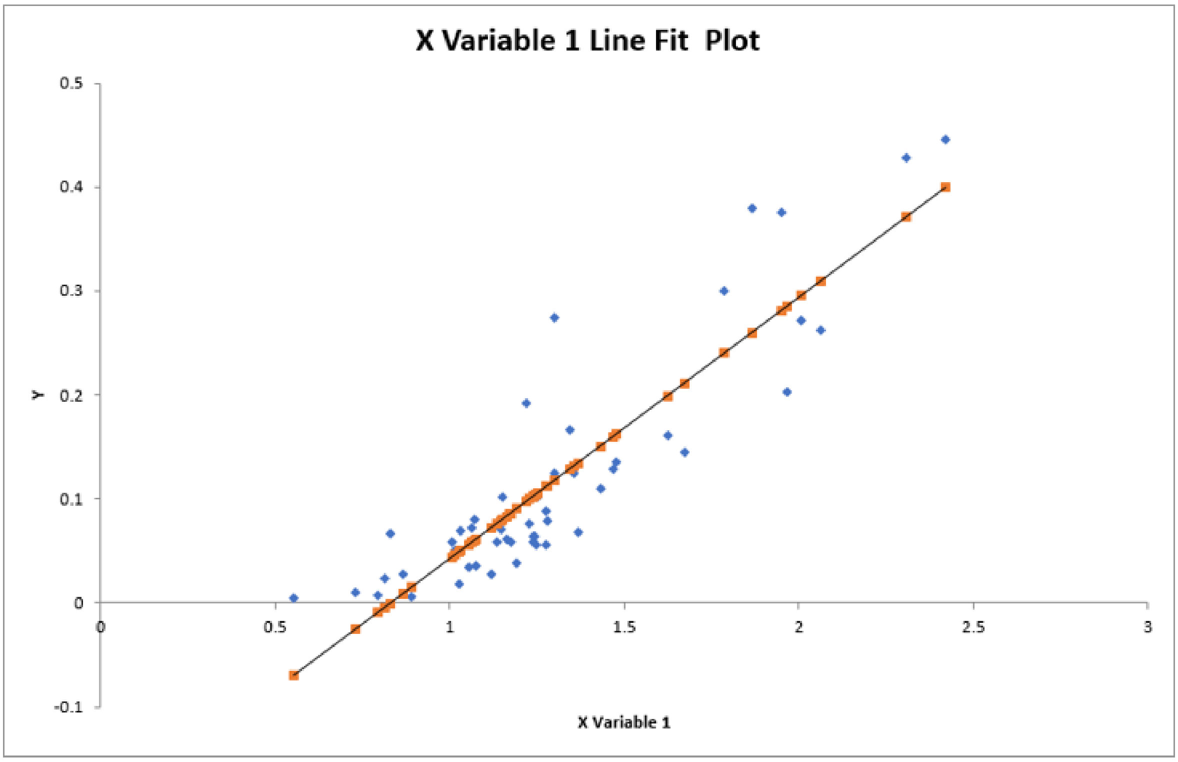


Figure 5: Graph showing mean flow in m/s (X axis) and mean load in kN.

As can be seen from the graph in Fig 5 as water speed increases there is a corresponding increase in force generated on the manikin in the water. Unlike the data collected by Onions and Collins (2017) with rafts in a similar application, the rescuer did not come up onto the plane with a subsequent drop in force. Discussions between the technicians and the research team (please see bios) led to an agreement that they had not experienced Rescuers using QRH coming up onto the plane.

However, if the expected drag force of this manikin in the water is calculated using the Rayleigh equation

$$\left(D = \frac{1}{2}CpAv^2\right)$$

In which where *C* is the drag coefficient, *A* is the area of the object facing the fluid, and *ρ* is the density of the fluid using the mean velocities of the 51 data sets obtained in this study then the blue line in Figure 6 is obtained (Benson, 2022). This line represents a rescuer whose profile to the current vector does not change as velocity increases. This line is in strong contrast to the mean loads generated by the data sets in this study. The conclusion drawn is that the Manikin/Rescuer in the water does change its profile in relation to the current vector as the velocity increases, though observation would not suggest the manakin planes as a raft does. Thus, although a linear increase in force is experienced it is not an exponential increase. These findings were borne out by the Technicians interviewed who reported experiencing a “rising up” feeling while positioned in the flow on a QRH, the diorsal attachment point ensuring the Rescuer stay in the surface water experiencing less drag.

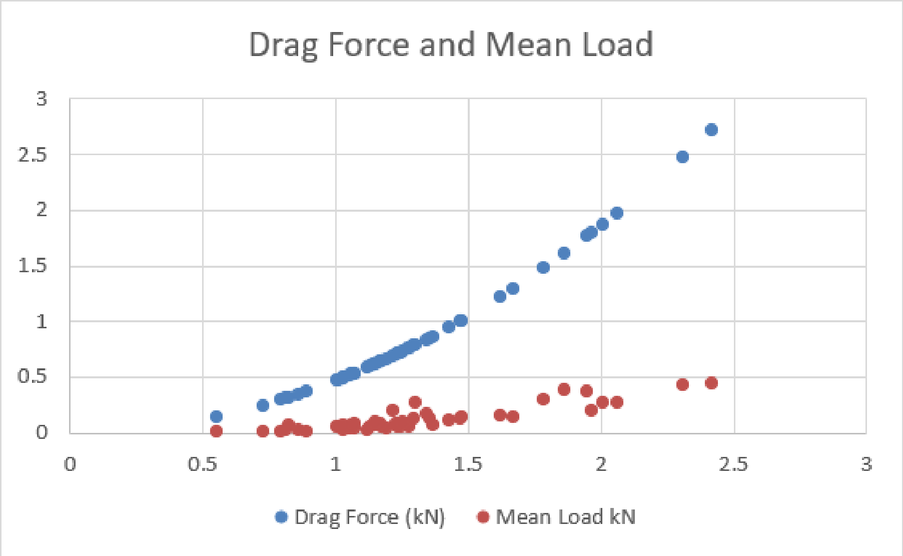


Figure 6: Graph showing Drag Force (blue) and Mean Load (Red)

Both Ferrero (2006) and Bechdel and Ray (2009) postulate that there is a point where the force of water on the Rescuer is too great for them to be able to operate effectively and that the rescuer does assume a defensive swimming position by virtue of the dorsal attachment point. The Technicians involved in the testing agreed that the higher water velocities, close to 2.5 meters per second, generating a force on the Rescuer of close to 0.5 kN experienced was towards the upper end of comfortable / effective for operation. Anything above 0.5 kN results in an unsustainable constant load on the Rescuer. This finding would align with a force of 0.623kN that has been shown to be the tolerable force for men pushed against a 100mm wide flat bar, QRH harnesses are typically 50mm although the foam of the PFD, we would expect to dissipate the load (Evans & Hayden, 1971). Tolerable forces for women were reported as being significantly less (Evans & Hayden, 1971). “These loadings are however, potentially, affected by various factors including age, gender and anatomical build” (Lee & Hughes, 2006).

Limitations of study and further research

Due to the large amounts of time required for the in-water Rescuer a manikin was used. While the use of a manakin allowed for a consistency in the tests, optimised water time, reduced risk, every effort was taken to ensure as realistic a positioning in the water as possible, it is conceivable that different results would be obtained by using a real body.

The manikin was clothed in a wetsuit rather than a dry suit, this may also have had an impact on the data. As a result of using a single manikin based on a male form the data obtained using female Rescuers may provide different results.

The highest water speed recorded in the test was 2.4 meters per second. However further research, at higher water speeds, would determine the situation in which the load on the user became unmanageable there is, however, an ethical and safety implication. It is suspected from the data obtained that the situation for the Rescuer in the water would very quickly transition from manageable to unacceptable both in terms of risk, ability to function and capacity for the Rescuer to release the QRH.

The location of the attachment point on the QRH requires further investigation. Several North American manufactured PFD's place the attachment point low on the PFD closer to the lower thoracic/ upper lumbar potion of the spine. European PFD manufacturers, position the dorsal attachment point on the PFD in the mid thoracic area. There is also variation in the attachment position following donning the PFD, some wearers preferring the PFD high on the body or low on the body, thus changing the position of the dorsal attachment point. Dorsal attachment point positioning may have an impact on the force experienced by the rescuer, their capacity to operate, and effect body position in the water. The load being spread via the PHD around the rib cage rather than across the stomach if positioned around the lumbar area. European Harnesses where used in this testing and positioned on the manakin for a mid-thoracic dorsal attachment point. Further research could be conducted to determine if there is an "ideal" attachment point, and optimum shape for the in-water Rescuer to minimise load on themselves, ensure operation and defensive positioning. Collins and Onions (2014) use of 'star' shapes to force QRH releases may offer some insight.

Conclusion

Use of a QRH from a highline represents an improvisation to a method that normally uses a raft or sled. "This is not a technique endorsed by Rescue 3 Europe" (Gorman 2020). However, this method might have application in locations with difficult bank access that would hinder deployment of large craft or the use of a V or Y lower. This method is a risky solution as it places the rescuer directly in the water, requires time to construct, high skill and judgement levels by the team. The limitation of using a QRH on a highline is the sustained loads on the rescuer. The loads generated are within SWL for the technical equipment used to construct the highline. The window of operation for the rescuer in the water is likely extremely small due to the sustained forces involved with a suggested maximum acceptable water speed of 2.5 meters per second, or loads on the rescuer that do not exceed 0.5kN even for an extremely experienced and capable rescuer. Dorsal attachment point position and height of the highline above water level may be additional factors and warrant further invetsigation. Both V and Y lowers represent simpler options that are self-limiting due to the belayers capacity to hold loads via moving, direct or indirect or body belays, this could form the focus of further studies. The implications for training and practice are that high levels of experience and judgement are required in electing to use a QRH in this manner and that use of a raft or sled are advised. This consideration was shared by our Technicians, who offered the view that, pragmatically, research time may be better employed exploring the capacity of a sled from a highline, consequently a final study of Sled on a high line is advisable.

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National White Water Centre, Canolfan Tryweryn for the use of their top site.
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Plas-y-Brenin the National Outdoor Centre for support with Rescue Technicians.
Rescue 3 Europe for support and the use of diagrams from their manuals.

Abbreviations

QRH	Quick Release Harness
PFD	Personal Floatation Device

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COMPARING INSOLE LENGTH WITH OUTSOLE MEASUREMENTS

Robert Speiden, B.S.E. and Joel M. Serrano, Ph.D.
Blacksburg Volunteer Rescue Squad
Search and Rescue Tracking Institute
United States of America
Email: robspeiden@blacksburgrescue.org

ABSTRACT

SAR resources, including visual trackers, conduct missions for thousands of missing persons every year. These missing persons, who may be wearing footwear, usually own additional pairs. To aid with track interpretation and possibly expedite finding the person, trackers can glean useful information from the other samples.

Relationships between footwear measurements are described for four parameters: insole length, outsole length, outsole width, and heel width. Insole lengths vary less than outsole lengths for individuals. The outsole length, outsole width, and heel width portray linear relationships to insole length with excellent, fair, and poor reliability: $R^2 = 0.95$, 0.84, and 0.65, respectively. The results of these findings provide footwear dimension predictions and offer benefits for clue interpretation.

KEYWORDS: Search and Rescue, Tracking, Footwear, Tracks, Dimensions

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INTRODUCTION

Thousands of searches for missing persons (also referred to as ‘subjects’) occur every year in the United States. From 1992 through 2007, the National Park Service alone conducted an average of 4090 search and rescue (SAR) operations per year (Heggie & Amundson, 2009). Countless law enforcement agencies and professional volunteer groups utilized a variety of resources to organize and conduct search efforts for those operations.

Tracking

Visual trackers are often one of the resources involved in organized search efforts, and footprint detection frequently occurs during those searches. Trackers look for footprints and interpret what they or other searchers find. Track interpretations consist of: direction of travel, speed of track maker, age of the track, etc.

Post-detection assessment of tracks includes determining the relevance of the footprints to the search. Just because a searcher finds a track does not mean that the track was made by the missing person. Speiden (2009/2018) states in *Foundations for Awareness, Signcutting, and Tracking*, “Not all sign will be relevant to the missing person.” As with any other potential clue found during the search effort, trackers should analyze footprints for likelihood of association with the subject. This assessment can rule out irrelevant tracks and prevent a waste of resources spent by assuming that a found track means that it was made by the missing person.

Research is being conducted on clues found during search efforts. Preliminary findings from 503 searches indicate that subjects’ footprints were found on 84 (17%) of those searches. Of those 84 searches, tracks were found by trackers on 56 (67%) of them, non-trackers found tracks on 16 (19%) of the searches, and the tracking training of the searchers that found tracks on the remaining 14% of searches was not recorded (Speiden, 2024). If these numbers are extrapolated to the annual average of 4090 searches that occur in US national parks alone, that suggests that trackers could find tracks on over 450 searches per year. While that is a very speculative number, it is nonetheless a hint at how significant a role tracks can play in pointing searchers towards the missing person. Even if trained and certified trackers aren’t assisting with a search, clue-aware searchers, by the same speculation, are likely to find tracks on hundreds of searches per year.

One factor used to assess the likelihood that the subject made a track of interest is the measurements of the track itself. Information about the dimensions of tracks assists trackers in determining tracks as either pertinent or unconnected to the search effort.

Subject’s Footwear

Gathering subject information is typically one of the first tasks in an organized SAR mission. Koester (2008) writes in *Lost Person Behavior,* “Investigation is the tool that helps determine the specifics of an individual.” Among many other bits of useful information (e.g., clothing they are reported to be wearing), search resources can generate intelligence about the missing person’s footwear through investigations.

The subject’s contemporary footwear (if indeed they don footwear) typically remains absent during the search phase of SAR. However, most subjects possess additional, accessible footwear which may aid searchers.

Narrowing the possibilities of probable measurements challenges even the best trackers. Determining the likely or probable range of measurements of a particular subject’s tracks is a difficult task. Discovering useful information requires a diligent effort. Track dimensions can be compared with the subject’s other footwear to determine if a track of interest is too small, too large, or is one that could reasonably have been made by the subject. Knowledge of a missing person’s footwear dimensions can aid track interpretation, and potentially accelerate finding the person.

A question about variation among insole and outsole lengths arose early in this process. That question was "Which, if either, varied more among all footwear belonging to an individual – their insole or outsole measurements?" The answer to that question would determine which dimension would be recommended as a reference for predicting the dimensions of tracks made by the missing person.

LITERATURE REVIEW

A literature search using the terms insole, outsole, footwear, dimensions, and/or relationship in PubMed, ScienceDirect, Semantic Scholar, Google Scholar, JSTOR, and ResearchGate yielded no publications or studies of relationships between footwear insole and outsole dimensions.

Recent publications describe tools being developed for the advancement of insole pressure measurements for sports (Krüger & Edelmann-Nusser, 2009) and fall risk assessment (Subramaniam et al., 2022), as well as an outsole measurement tool for slip prevention (Whitson et al., 2018).

Giles and Vallandingham (1991) discuss relationships between foot, footwear, and footprint measurements with regard to a persons' height but do not include footwear insole measurements or specific outsole measurement techniques.

Forensic descriptions of insole investigations focus on comparing identifying features found on insole surfaces with those of inked impressions from suspects' feet, but there is no mention of any relationship to outsole dimensions (Abbott & Germann, 1964), (Bodziak, 2000), (Bodziak, 2017), (Cassidy, 1980).

Many websites show how to determine the size of a shoe based on foot measurements, but none were found that discuss the comparison of the insole to outsole measurements.

METHOD

Individual variations

Insole lengths and outsole lengths were measured with a 17mm-wide tape measure for multiple pairs of footwear from each of five individuals. The sample size from the five individuals consisted of 7, 8, 14, 20, and 22 items of footwear for a total of 71. The range of lengths was then calculated by subtracting the shortest length from the longest length.

Insole outsole dimensions

In an attempt to reflect typical footwear missing persons were found wearing, a variety of footwear such as minimal shoes (e.g., flip flops), sneakers, and boots was included. Steel or composite-toed footwear, high-heels, novelty shoes, and other specialized footwear were excluded since they were not found with missing persons (Speiden et al., 2024).

Measurements of three hundred pieces of footwear yielded four data points for each piece: Insole Length, Outsole Length, Outsole Width, and Heel Width.

The **insole length** was measured by inserting a 17mm (½”) wide tape measure into one item (right or left) of each pair of footwear with the leading edge of the tape measure pushed to the front of the toe. The tape was held flat against the floor of the insole. The tape was then bent at the rear edge or rise of the heel (See Figure 1a). The reading at the heel was made as closely as possible to the point at which the rise (vertical slope) equaled the run (horizontal aspect). The measurement was read and recorded to a precision of 1mm with an estimated error of ± 2mm due to curvature at the heel.

The **outsole length** was measured by hooking the tape at the front of the outsole and reading the length at the back edge of the heel (See Figure 1b). When measuring a rounded or sloped edge, the length was read as the distance between the two closest points where the rise equaled the run.

The **outsole width** was measured at the widest part of the footwear, in the ball area of the footwear. The authors used this preferred measurement location vis a vis their observations on real-world searches that formed part of a previous study (Speiden et al, 2024). All footwear worn by subjects documented in that study was widest at the ball portion of the sole. To measure the outsole width, the tape measure was hooked on one side of the outsole then the width was read at the opposite edge of the outsole (See Figure 1c). The distance between the two closest points where the rise equaled the run yielded the measurement for outsoles with rounded edges.

The **heel width** was measured at the widest part of the heel or rear portion of the outsole. Hooking the end of the tape measure on one side of the heel then reading the width at the opposite edge of the shoe provided this measurement (See Figure 1d). The distance between the two closest points where the rise equaled the run yielded the measurement for outsoles with rounded edges.

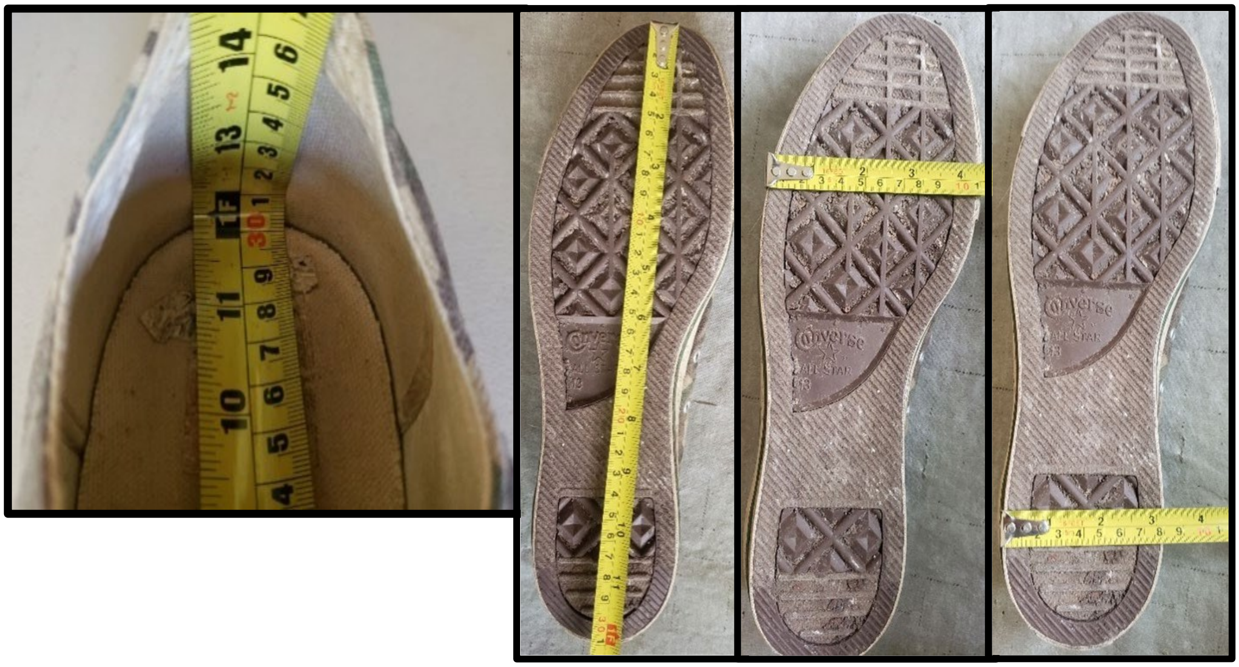

Figure 1: *Footwear measurements from left to right: (a) Insole Length (b) Outsole Length (c) Outsole Width (d) Heel Width.*

RESULTS

Individual Variations

Figure 2 shows the range of insole and outsole lengths for the five individuals. Insole length ranges varied from a minimum of 17mm to a maximum of 40mm with an average of 28mm. Outsole length ranges varied from a minimum of 32mm to a maximum of 51mm with an average of 41mm. The average outsole lengths varied 13mm (46%) more than the average insole length range.

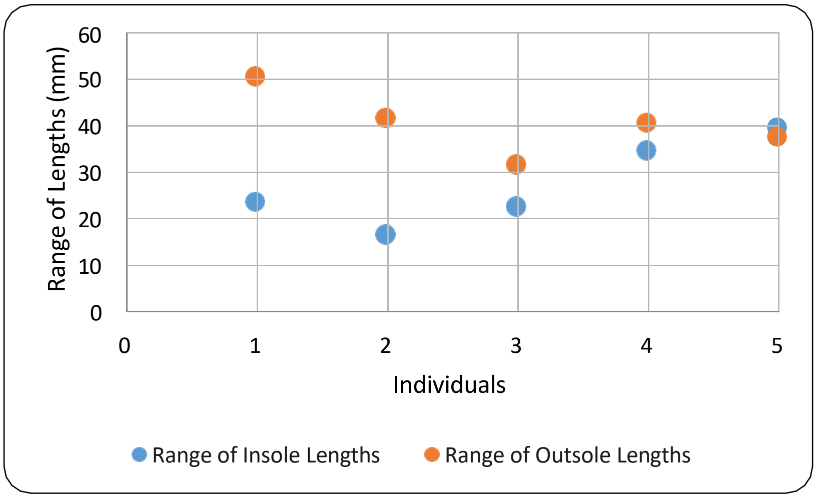

Figure 2: *Individual Insole and Outsole Length Variations*

Insole Outsole Dimensions

Outsole measurements (outsole length, outsole width, and heel width) were analyzed with regard to the insole length. The insole length was utilized as the independent variable. Outsole length, outsole width, and heel width all exhibited positive linear relationships with respect to insole length, as shown in Figure 3.

The minimum and maximum values for the insole length were 105mm and 337mm, respectively. The minimum and maximum values for the outsole length were 121mm and 372mm, respectively. The minimum and maximum values for the outsole width were 63mm and 135mm, respectively. The minimum and maximum values for the heel width were 43mm and 110mm, respectively. The outsole length displayed a notably higher contiguous increase than the two widths. Due to a larger variation in the outsole lengths than either of the width measurements, the researchers expected this discrepancy, (Table 1).

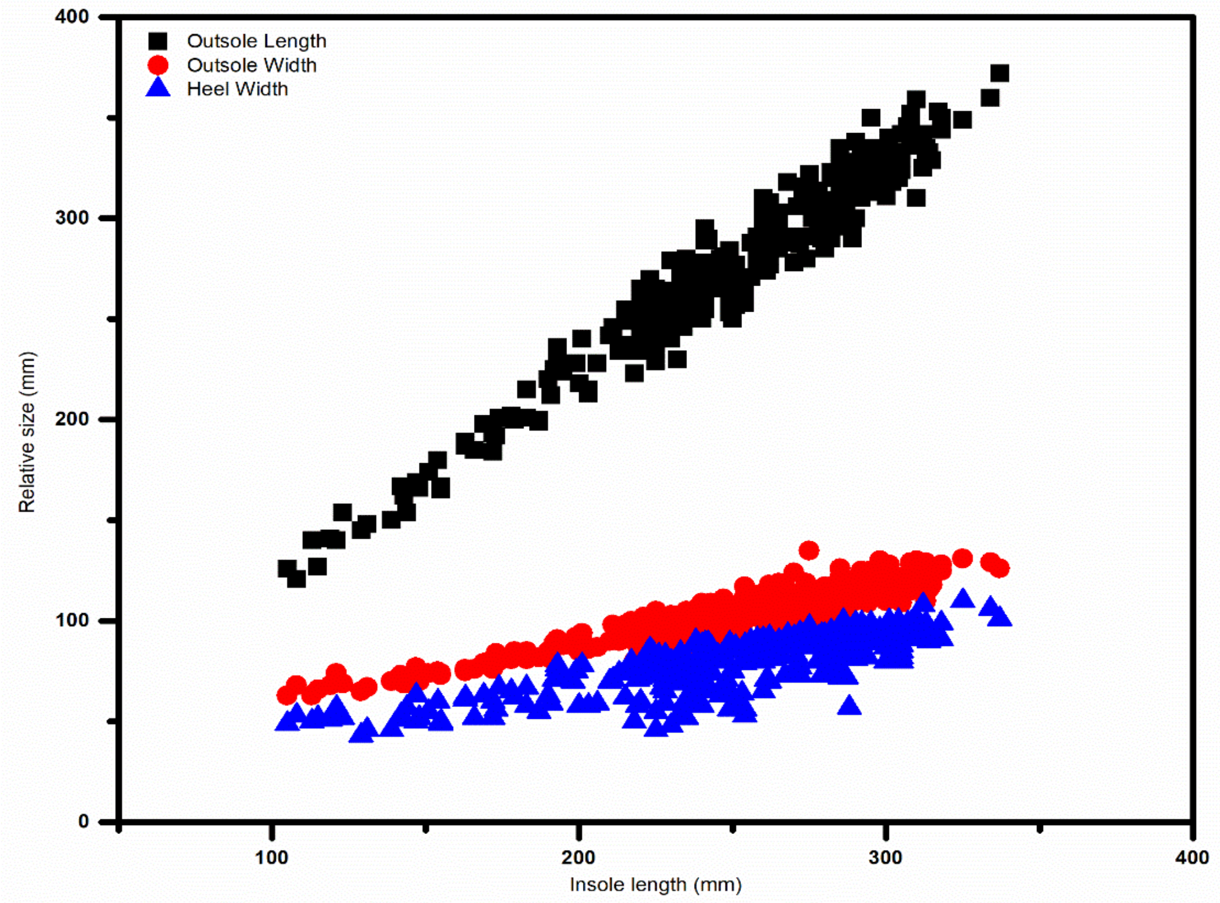

Figure 3: *Plot of data collected for insole length and associated outsole measurements overall length, overall width, and heel width.*

Linear modeling

The linear relationship was analyzed with the sum of least squares fit between the insole length versus outsole length, outsole width, and heel (see Table 1). The equation produced for the outsole length exhibited the highest R^2 value of 0.95, followed by the outsole width and heel width models which yielded R^2 values of 0.84 and 0.65, respectively.

Introducing a 21mm margin of error ($L_O = 18\text{mm} + 1.03 \times L_I \pm 21\text{mm}$) (where L_O = outsole length and L_I = insole length) encompassed a 95% confidence interval for the relationship between insole length and outsole length. The 95% confidence interval ($p<0.01$) included a range of the resultant outsole length value of that equation, plus or minus 21 millimeters (0.83 inches).

In addition to a range that varied from -3mm to +39mm (-0.1” to +1.5”), 95% of measured outsole lengths included 1.03 times the insole length. For both the outsole width and heel width, however, the poor fit model suggests that, when compared to the insole length, such dimensions are unreliable for predictable values.

Dimension	Minimum	Maximum	Linear equation	R^2	95% PI[a]	95% CI[a]	90% CI[a]
Insole length	105	337	-	-	-	-	-
Outsole length	121	372	$L_O = 18 + 1.03L_I$	0.95	21	16	11
Outsole width	63	135	$W_O = 29 + 0.295L_I$	0.84	30	-	-
Heel width	43	110	$W_H = 18 + 0.250L_I$	0.65	20	-	-

[a] value is given for ± of the L_I-intercept in mm

Table 1: *Data values and linear models for insole length (variable L_I) compared with outsole length (L_O), outsole width (W_O), and heel width (W_H) including prediction intervals (PI). All units are in millimeters.*

DISCUSSION

Individual variations

Of the five individuals sampled for the range comparison, for four of them, the outsole lengths varied more than the insole lengths. With regard to the one individual for which the insole lengths varied more than the outsole lengths, the discrepancy was the smallest among all of the individuals at a mere 2 mm. The comparison of insole and outsole length measurement ranges between five individuals showed a clear, though not absolute, propensity for outsole lengths to vary 46% more than insole lengths. This demonstrates that the insole length is more reliable than the outsole length for use as an independent variable in predicting track dimensions.

Relationship of insole and outsole lengths

By applying the outsole length linear model $L_O = 18 + 1.03L_I$, the median value for an outsole length should be between 21mm and 28mm greater than an insole length. In order to display the probability of outsole length, measurements of outsole length minus insole length were subdivided into 12 groups of five mm increments: 0-4mm, 5-9mm, 10-14mm, etc. The distribution closely fits a normalized Gaussian probability distribution (see Figure 4). The maxima resided at 26mm, which indeed corresponds to the previous linear model prediction as well.

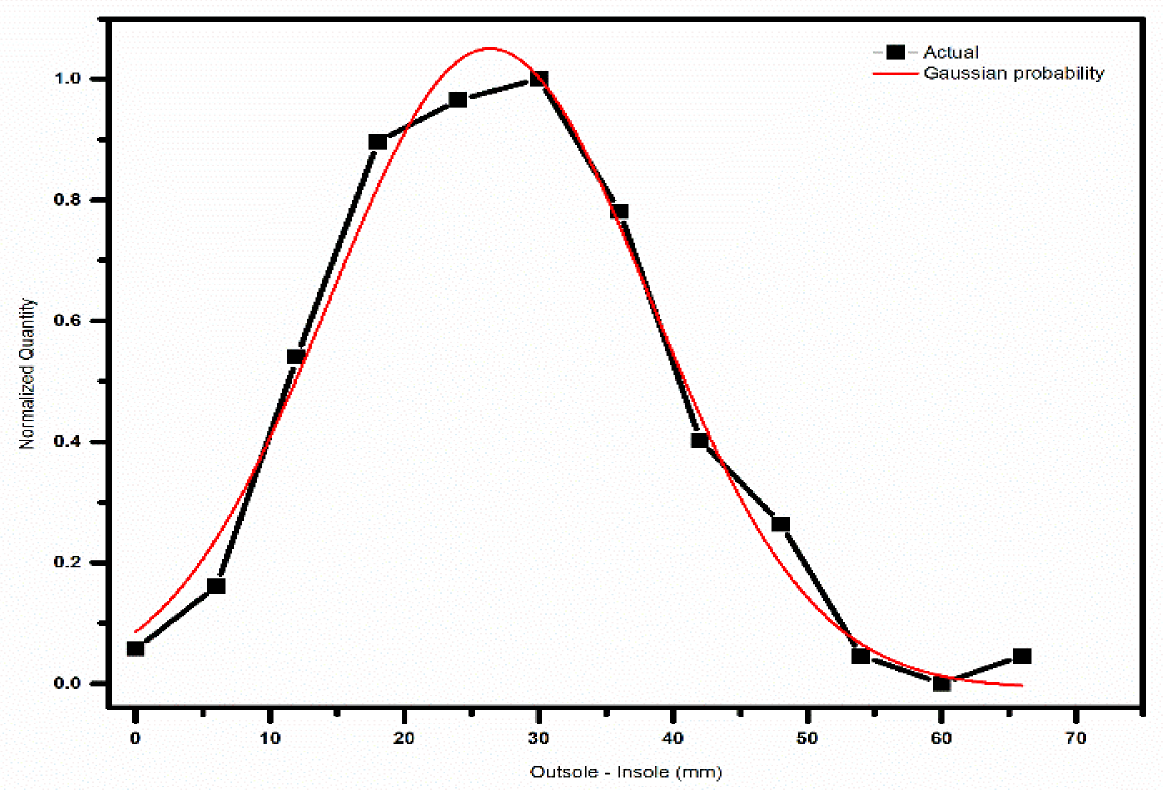

Figure 4: *A normalized distribution of outsole length less insole length for the body of samples measured. The black line represents the actual data measured. The red line represents the modeled distribution of the data.*

The probability distribution highlights the likelihood for real-world applications. Probability for footwear with zero difference in outsole to insole remains very low. Footwear types such as high heels and wedge shoes, however, do exhibit a zero or even negative differential value. Since those types of footwear have not been documented in missing persons cases (Speiden et al., 2024), they were excluded from this research. For the confines of this study, the 95% probability for differential lengths resides between 4mm and 51mm (see Figure 5).

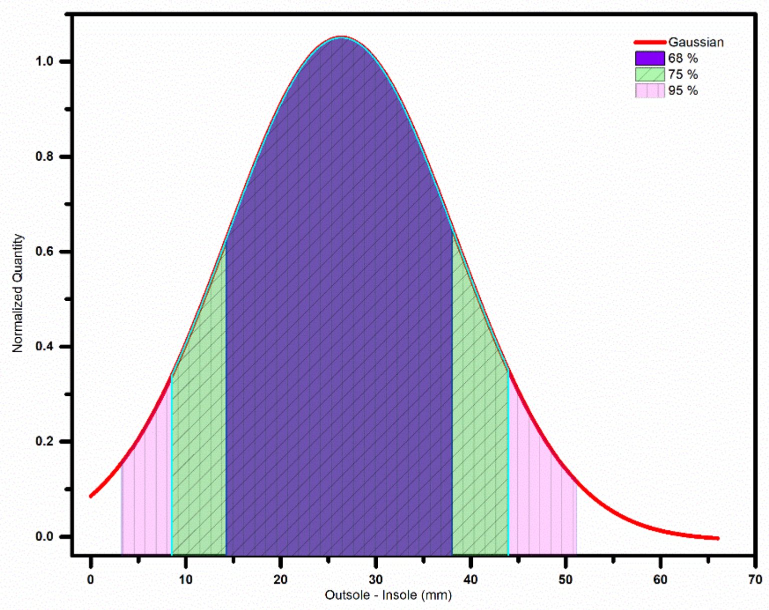

Figure 5: *Normalized distribution with prediction probability bands for 68%, 75%, and 95% overlaid.*

Comparing dimension relationships

As a comparison of the three resulting dimensions which are predictable based on the insole length (outsole length, outsole width, and heel width), the most reliable with the smallest range is the outsole length. This data suggests, as a result of the R^2 values (Table 1), that there are larger margins of errors in predicting the width of the sole or heel based on the insole measurement.

Furthermore, the field application for trackers would benefit from larger dispersion of values for prediction measurements. A small change in search values (outsole length, outsole width, and heel width) which the tracker will be evaluating would ideally change with insole length inputs. To illustrate this, Figure 6 shows the effects of different insole lengths for prediction values in resultant measurements.

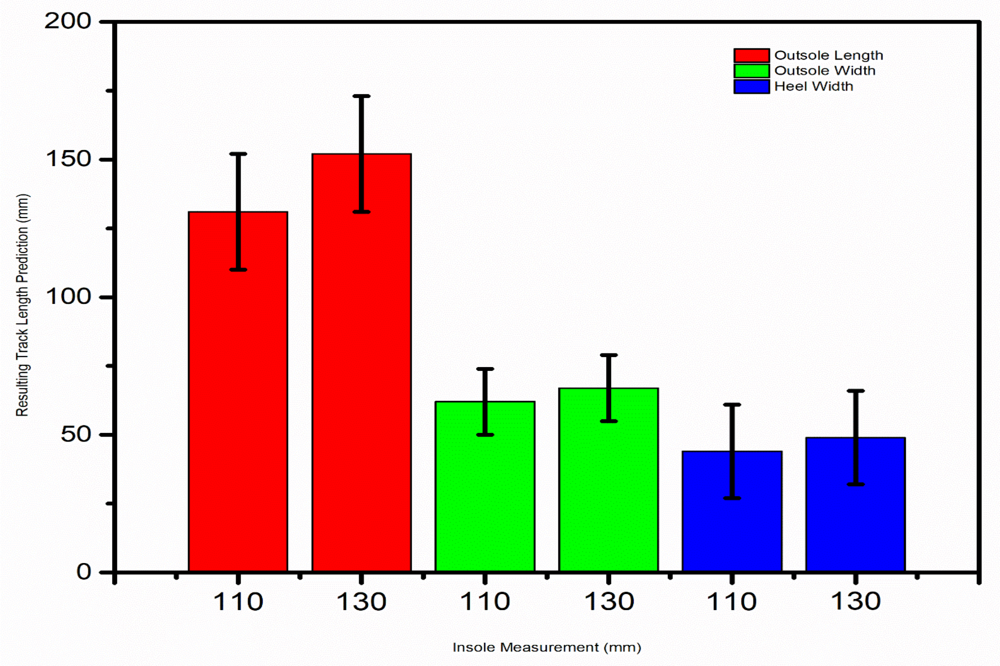

Figure 6: *Graph showing overlap of prediction band changes with a difference between insole length measurements*

As an example, Figure 6 shows the difference in predicted values with a 95% prediction band for outsole length, outsole width, and heel width. The larger the overlap of the error bars means the lower the distinguishing ability for trackers in the field. Note that the smallest amount of overlap exists for the outsole length based on the two different insole measurements of 110mm and 130mm. Based on both the R-squared values and the larger differentiation of prediction values, outsole length has the highest reliability for determining potential versus non-potential tracks of interest. Therefore, the outsole length versus insole length regression with the 95% prediction band provides the highest utility among all of the outsole dimensions for trackers and rescuers (Figure 7).

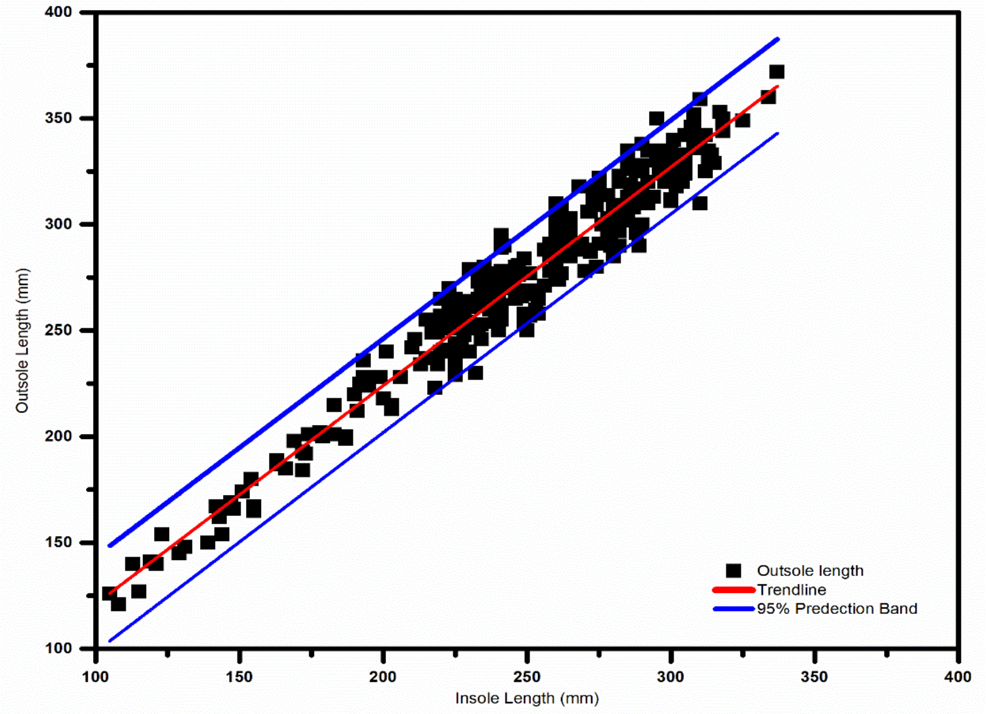

Figure 7: *Linear modeling of the outsole length versus insole length with upper and lower 95% prediction bands for footwear with insole lengths between 105 and 337 mm*

Insole measurement alternative

Another method of measuring the insole length is to remove the insole from the footwear and then measure it. The advantages of this technique include the reduction of error from the size of the tape measure, as well as the ability to measure the overall width and the heel width. There may be a sensitive issue with the act of taking apart a missing person's footwear in front of the family who is likely already distressed. Reducing that potential awkwardness may be as easy as asking permission to measure the insoles, which can be facilitated by offering a simple explanation of the reasons for the intrusion. Removing the insole and gathering these measurements can also be completed out of view of the family members. Other circumstances (e.g., not all insoles are removable) may also present difficulties related to externally measuring insoles. Nonetheless, insole length determinations often require internal measurement.

CONCLUSIONS

Thousands of searches for missing persons occur worldwide each year. Myriad resources, including visual trackers, assist with searches for missing persons. As part of a tracking team that wants to find and follow tracks made by the missing person, trackers' initial goals are to seek, locate, and interpret tracks. They should also be able to rule out tracks made by people who are not missing (unless another person was involved in the subject's disappearance). Necessary interpretations of tracks of interest include their relevance to the search effort.

In the absence of any information about the subject's shoes, challenges arise while sorting out the subject's tracks from those of anyone else. These challenges include searchers walking around the search area. Having some information about the subject's footwear helps narrow possible tracks via a process of elimination.

In the quest for footwear information, the insole lengths were determined to vary less than outsole lengths for a variety of footwear owned by individuals. Four distinct measurements from 300 pairs of footwear were then gathered and analyzed. Those measurements consisted of insole length, outsole length, outsole width, and heel width. The strongest correlation exists between the insole length and the outsole length. The focus of this study was on developing a base of information that could help interpret tracks that may have been left by, and therefore lead to, a missing person.

No prior research or publications on this topic was discovered. This research provides a scientific understanding for tracking via track interpretation in future search missions and offers a foundation for additional studies relative to this topic.

Even though it is not possible to measure footwear the subject may be wearing, the measurements of other footwear belonging to the subject can give valuable information. Additional research shows the relationships between the insole length(s) of footwear and the owner's foot size (for unshod cases) and footwear (for shod cases). Although missing persons often lose their footwear, key footwear information can also indicate probable measurements of unshod (barefoot or sock-clad) footprints (Speiden & Serrano, 2024).

Using the model developed in this research, any track of interest may be quickly assessed as plausible or improbable based on the relevance to the missing person. Based on this study, trackers may apply a simple field method for assisting in tracking missions. Trained trackers are advised to measure the insole lengths of three pairs of footwear belonging to a missing person (minimum of one is required).

Using the length of an insole provides a 47mm (2") window of probable outsole lengths. The window of probabilities can therefore be used to include or exclude outsole lengths and track lengths found on a missing person search. This flow-chart (Figure 8) assists with drawing conclusions and potentially serves as a feasible field practice for visual trackers.

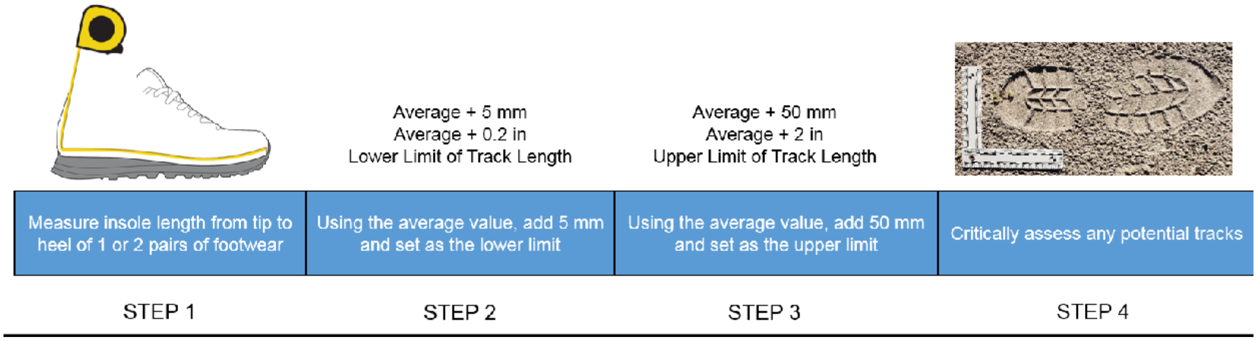
Average + 5 mm
Average + 0.2 in
Lower Limit of Track Length
Average + 50 mm
Average + 2 in
Upper Limit of Track Length
Measure insole length from tip to heel of 1 or 2 pairs of footwear
Using the average value, add 5 mm and set as the lower limit
Using the average value, add 50 mm and set as the upper limit
Critically assess any potential tracks
STEP 1
STEP 2
STEP 3
STEP 4

Figure 8: *Flow chart for process of incorporating the findings of this study into practice*

ACKNOWLEDGEMENTS

The authors would like to thank the JSAR reviewers for their contributions, Melissa Weeks for her keen eye and professional editing skills, and those who devote their time and energy to searching "…so that others may live".

RESEARCH LIMITATIONS

The footwear measurement data included in this study were collected by measurements with a tape measure. While more precise and accurate methods are available, the tape measure is the tool that trackers most consistently use to get footwear and track measurements during search operations.

Due to lack of reported prevalence with some types of footwear (e.g., wedges, high heels, etc.), this study excluded those in research of footwear worn by missing persons (Speiden et al., 2024). These exclusions tended to exhibit outsole lengths shorter than insole lengths. Should a missing person be known to wear any of these types of shoes, it is recommended that consideration be given to adjusting the range of shod track length.

The comparison of the length of a track to footwear dimensions requires a complete track. Partial tracks are typically found more often than complete tracks, but a full track length is necessary for an accurate comparison with footwear measurements.

ADDITIONAL RESEARCH

To increase the rigor of the results, an additional study recommendation is to gather more data similar to this study. Practical applications of this research include two avenues. This study narrows the possibilities of dimensions of tracks made by footwear that missing persons are wearing. This study can guide further research regarding dimensions of missing persons' footwear and dimensions of associated footprints. As mentioned in the introduction, research is also being conducted to gather data on clues found at searches.

Research related to this paper is underway and encompasses several topics. Those topics include insole measurements with tape measures that have different hook areas, as well as correlations between insole length and track dimensions. Research that describes relationships between insole length and unshod foot length, as well as insole length and shod footprint length is currently being written. Research is also being done to describe changes to the dimensions of footwear measured in this study compared with age of footwear, be that age time or distance that footwear has been worn.

ABOUT THE AUTHORS

Robert "Rob" Speiden holds a bachelor of science in engineering degree from Virginia Tech. He is an active member of the SAR community and has assisted with well over 450 searches since 1993. As a member of several SAR groups, Rob responds to searches in the mid-Atlantic region of the U.S. serving the roles of certified Tracking Specialist, Search Team Leader, and Search Mission Coordinator.

Rob has been an instructor and evaluator for the Virginia Department of Emergency Management (VDEM) since 1998. He is also certified as a Trailing Evaluator for Cybertracker Conservation. As the VDEM Lead Tracking Instructor, and through his Natural Awareness Tracking School, he teaches map/compass/GPS skills, Lost Person Behavior, and Tracking classes (for humans and other animals) to search and rescue volunteers, law enforcement officers, and government agents around the world. Rob has authored and published three SAR tracking books: *Foundations for Awareness, Signcutting and Tracking*, *Tracker Training*, and the *Pocket Guide to Human Tracking for SAR*.

Joel Serrano earned his Ph.D. degree in Chemistry from Virginia Tech. He is an EMT and Search Team Leader with the Blacksburg Volunteer Rescue Squad. Joel is an Operational Tracker with the Search and Rescue Tracking Institute, and he is certified as a Level I Tracker in the Cybertracker Conservation program. Through the scientific lens, Joel seeks to alleviate human suffering, if even only for a moment.

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Measuring the quality of the search activity

Paul Duffy MInSTR, MLPI
and
Ian Plater Dip Specialist Rescue, MInSTR

L&MPS International

Email enquiries@lampsinternational.co.uk

**Letter to the editor.*

Dear Editor,

As Search & Rescue practitioners and trainers delivering to experienced full-time and volunteer searchers, a subject discussed with those who have been responsible for the coordination, management, or command and control of lost and missing person incidents is how do we measure the quality of the search activity that has been carried out on our (and our missing person's) behalf by the assets that have been identified, briefed, tasked and de-briefed by us?

The results of this discussion on the functioning of search assets, often leads to a response that fails to show as high a level of confidence (or assurance) as would be expected or desired. Although not always specifically mentioned or listed within post-incident lessons learnt reports, public enquiries or coroners court findings, there are many examples of missing persons being ultimately located, often by members of the public long after search operations have been suspended or terminated, in areas that have already been searched and considered completed from a tactical perspective.

This is important as a an apparently poorly coordinated and unsystematic search will damage reputations (both individual and an organisations'), will lower trust and confidence in statutory and voluntary bodies and can potentially increase the risk of a fatality for the missing person. Highlighted in the media, headlines such as those below illustrates the case.

'Surrey diver doesn't believe missing is in the River Wyre' (Ng and Manning, 2023)

On the 27th January 2023 a 45-year-old was reported missing. 23 days later and after multiple searches, her body was found by members of the public in an area considered searched.

‘Search expert’s frustration during hunt for missing Dorset teen‘ (Minchin, 2022)

On the 7th November 2019 a 19-year-old female was reported missing. 11 days later, after multiple searches, her body was found less than a mile from where she went missing. This was also less than 300 metres from items of clothing that were located by a member of the public on the 16th November and in an area already covered by more than one search asset.

As we know, lost and missing person search often involves a joint response from a range of individuals and agencies. Each person in this group seeking the person(s) reported missing is acting in either a statutory, professional or spontaneous volunteer capacity. Completed search activity by an asset is normally fed back, debriefed and reviewed by the search management team with any results informing further action. There are many ways that feedback and results can be provided by search assets to their search management team. However, at this time, there are not consistently accepted national or international methods that are both qualitative and quantitative.

The authors believe that this leaves a gap for a method that mitigates the risks and limitations evident in a significant number of incidents. Initial searches (Google Scholar etc.) for studies that have already conducted research into areas such as ‘failures in search assurance’, ‘an evaluation of missing person search efficacy’ or ‘errors in the use of Probability of Detection and/or Area’, have failed to locate any content that specifically covers this concern.

However, within the ‘Compatibility of Land SAR Procedures with Search Theory (Cooper et al, 2003), the authors make reference to a ‘restriction’ that ‘*simply means that searching does not guarantee detection, even if the search object is in the area when it is searched. SAR search planners the world over have seen this property of SAR searches demonstrated all too often.’*

Also, there does not appear to have been any formal studies carried out to evaluate those conjectures by SAR professionals for why search teams miss, such as:

1) Search management sending to the wrong location.
2) Search management tasking insufficient (or the wrong) assets.
3) Search management failing to resource mix (or tasking only one type of asset).
4) Team searched in the wrong area.
5) Team did not complete their task and left their area with the subject unfound.
6) Team deliberately missed part of their search area and failed to identify this to search management.
7) Team spacing was too wide.
8) Team did not check a unique feature within their search areas that hid the subject.
9) An individual searcher either missed or failed to recognise the subject.

As a 'positive declaration intended to give confidence' a calculation of search assurance ensures that those search assets tasked to a missing person incident adopt a coherent approach in evaluating their search activity and are able to provide the results of their activities as part of a structured debrief. We suggest that by evaluating the level of search assurance taking into account recognisable impact factors will allow those responsible for the coordination and direction of a search response to 'calculate' the probability of locating an item sought (the missing person, or items attributable to them). A further significant benefit would be a structured and targeted approach to subsequent taskings.

The United Kingdom has already made some progress with regard to search assurance, with members of the UK Police Search Governance Board agreeing a definition for Level of Assurance. We believe time spent in developing a universally consistent method of reporting search activity will lead to a measurable level of search assurance, an opportunity to remove areas of uncertainty, provide data that can inform the search strategy, increase confidence in search assets (often with differing skill sets and operating procedures), provide evidence for future reviews and ultimately increase the levels of efficiency within lost and missing person searches.

The authors recognise that there is work to be done in the research and testing of this idea but believe that given public expectations, the continued development of a search assurance methodology should be considered an essential requirement for those undertaking, managing and coordinating a search response. The authors are seeking individuals and organisations who are interested in a collaborative approach to developing this concept.

Yours faithfully,

Mr Paul Duffy MInSTR, MLPI
Mr Ian Plater Dip Specialist Rescue, MInSTR

L&MPS International

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A review of the leadership and management culture and practices in a UK Search and Rescue Charity

Andy MacAuley BA(Hons) PgCert MCPARA MinSTR MICPEM

Former Chair of Trustees; Life Member – West Mercia Search and Rescue

Email: andy.macauley@westmerciasar.org.uk

**Letter to the editor.*

Dear Editor,

Abstract

West Mercia Search and Rescue (WMSAR) is a UK registered charity which provides a team of personnel to assist the emergency services with missing-person search and water rescue.

It has no paid employees, and voluntary members must actively participate in fundraising, maintenance, logistics, training, operations, and administration.

Its leaders are not specifically trained in people-management, business, or leadership by the charity, and must rely on any formal, informal, or instinctive leadership practices that they have developed externally to the charity.

This review [taken in late 2022] highlights the need for leaders to develop vision, values, and authenticity in their management of volunteers, but recognises that they are themselves volunteering. It explores motives for donating time and suggests leadership approaches which may be beneficial in terms of personal development for those leaders.

A small number of contemporary leadership theories are presented, and the current leadership is examined against these by both anecdotal experience of the author and responses from the surveys.

Recommendations are made where it is shown that there could be direct benefit from embracing one or more of the contemporary leadership theories and posed in the context of the charity.

The aims of the recommendations are to inform WMSAR and similar voluntary bodies' leadership on possible improvements, and outline a structure for better communication of vision, values and ultimately the next generations of leaders where the charity has a high turnover of volunteers. This will result in a reduced burden of handover, better teamwork, and sustainability for the charity. These recommendations may be applicable to other similar voluntary bodies.

Keywords: Leadership, Volunteering, Volunteer Management, Charity, Management, Rescue, People Management

Introduction

West Mercia Search & Rescue (WMSAR) is a wholly voluntary charity of 70 members, which fundraises to provide training and equipment for its own members as a missing-person and flood-rescue search team. The charity is governed by national standards, ultimately answerable to the Department of Transport, and is audited by Police and Fire services.

Four Executive Trustees are elected on a two-year tenure. Two further non-executive Trustees are co-opted.

A management team oversees daily tasks of operational and charitable activities. These positions are appointed by Trustees from the membership based on aptitude, which is usually linked to outside employment experience.

Member ages range between 21 and 70 years old: 8 Baby-Boomers, 18 Millennials and 2 Generation Z, with the remainder Generation X. 10 percent of members are female. All identify as their birth gender and two identify as LGBTQ+. There is one non-white-British. All members fall within L2-L8 socioeconomically.

The personal cost of fuel and equipment for members is between £500-1000 a year. Average attendance at events is over 100hrs/year. Time donated to charitable admin is estimated to be around 10,000 manhours per year.

Charity communications are by WhatsApp message and email. Face-to-face meetings happen ad-hoc at other events with whoever is in attendance, with an annual AGM being the only whole-team meeting.

Current leadership and management culture and practices

WMSAR's leaders are volunteers. Understanding the motivations behind their original membership better frame progression in the organisation.

The urge to help others is predominant in voluntary rescue (Shae, 2019; Martens, 2017), and this is exhibited in Appendix 2. Perry and Wise (1990) describe the notion of "Public Service Motivation", acknowledging three motives: skill maximisation, conformity, and emotional fulfilment. These motivations have been explored by Costello, Homberg and Secchi (2020) in a volunteering context, who established that those with greater sense of self-sacrifice are more likely to volunteer. They also show a link between motivation and volunteering intensity which is explored by Einold and Yung (2018) who use the phrase "Super-Volunteers" to describe those who donate 500 hours a year and go on to describe some of the challenges of managing these personalities. WMSAR leadership team is comprised wholly of members who donate hundreds of hours per year (Appendix 1).

Although Einold and Yung (2018) assume that managers are paid employees leading volunteers, they recognise that "Super-Volunteers" require a bespoke, time-consuming management with personal attention to each member. This, perhaps, informs the results of Appendix 4, where WMSAR leaders indicate some detraction from their enjoyment of volunteering associated with the burdens of people-management.

However, the motivations for leaders' continued service in the face of this detraction may be seen in Appendix 3 (3.2) where pride is universally evident and leaders have developed a "collaborative mindset" (Septianto et al., 2018); being proud of their own involvement has reframed to become pride in the team's efforts.

Perkins (2019) suggests a qualitative approach to assessing organisational culture, which informs the survey in Appendix 3. The dominant "story" (Perkins, 2019) from members is one of teamwork and camaraderie, which is a common theme in volunteering studies (Bidee et al., 2017; do Nascimento et al., 2018). Perhaps surprisingly, the achievement of saving lives is secondary. Groysberg et al. (2018) highlight the importance of aligning culture and strategy, and this disparity could be an issue which we see in Appendix 3.6 & 3.9, where team-building and hierarchy is in demand more than individual development opportunities. Indeed, Einold and Yung (2018) identify that "Super-Volunteers" crave teamwork and structure within which to exercise their own initiative. WMSAR do not currently have teambuilding as a priority in their strategy and this is a consideration for development.

Appendix 3.3-5 suggests that there is a broad agreement of the charity's values and belief that these are reflected by the leaders, which is a fundamental part of authenticity (George, 2015) and trust between members and leaders (Dan-Shang and Chia-Chun, 2013). However, some suggest that there is an opportunity to improve communication between leaders and members, which is a key part of maintaining brand evangelism and enthusiasm (Hague, 2019). The challenge of communicating to the membership remotely during COVID was detrimental to team cohesion (Appendix 3.3-5) and to restore motivation and identity, face-to-face communication must return (Alan-Livernois, 2020).

A lack of leadership training could be identified as a factor in some of the responses where “autonomy-supportive leadership” (Oostlander et al., 2013) is questioned. Ellis (2013) summarises well with the notion that volunteering your own time doesn’t necessarily mean you understand why others volunteer theirs. WMSAR does not offer leadership training and this is a consideration for development.

A minority of respondents to Appendix 3.6/9 plea for fairness in what they see as inequalities. Perceived “status” (Hays and Bendersky, 2015) in WMSAR is often earned by higher attendance and being a “Super Volunteer” (Einold and Yung, 2018), and rewarded with training opportunities. This could be perceived differently to “Elected Power” (Hays and Bendersky, 2015), and is likely to meet with more resentment. WMSAR strategy has been to train members who are most likely to attend an incident in as many roles as practical, maximising the chance of their skills being available. This strategy may encourage feelings of lesser support and inequality by lower-attending members (Kurtessis et al., 2015), but offers a logistical challenge for management which seeks to deploy a multi-skilled team for different environments.

Analysing contemporary management theories

Gordon (2021) identifies four contemporary leadership styles as follows.

Transformational Leadership

Transformational Leaders (Downton, 1973) use charismatic appeal to inspire with a sense of wonderment, establishing a cultural aspiration and vision within an organisation (Bass and Riggio, 2006). Contemporary examples are Elon Musk and Steve Jobs. It exists at one end of the Full Range Leadership Model (Avolio and Bass, 1991) as a recognition of the effectiveness of character, or “natural-born-leadership” (Haraida and Blass, 2019). The theory is dependent on the leader being a clear communicator of the organisation’s mission (Burgess, 2016) and is reliant on communication media and opportunities (Martic, 2020), but critics argue that a single leader who inspires others to work for the benefit of the organisation rather than their selves has a moral dilemma, and the opportunity to exploit that position (Mullins, 2007: 383). Critics also demonstrate that Transformational approaches alone do not work, and there is a requirement for some direct feedback in some situations, which are said to be traits of Transactional, or reward/discipline management (Burgess, 2016).

Leader-Member Exchange (LMX)

This theory (Graen and Uhl-Bien, 1995) focusses on interpersonal relationships between a leader and a member where output depends on a mutual respect and willingness to work together (Gordon, 2021). It relies on trust and balance between the moral obligation and “ethical responsibility” (Babic, 2014) of member and leader. The benefits of a good relationship increase motivation and belonging, and reduce conflict, but a poor relationship can result in demotivation and poor output (Furnes et al., 2015), and resentment when better relationships are observable (Gordon, 2021). A fundamental problem with LMX is that it is time-consuming (Haynie et al., 2018) and therefore difficult in a voluntary capacity.

Servant Leadership (Greenleaf, 1970)

Choosing to facilitate the needs of the individuals in the team, rather than to work towards your own goals is an act of humility (Tarallo, 2018) which ends in sacrifice of one’s own development and is rooted in a love for developing communities and people (Matteson and Irving, 2005). Septianto et al. (2018) suggest that leaders feel vicarious enrichment from the progression of others and the organisation, and this may be evident in Appendix 4. Tait (2020) reports that this produces great productivity but must be approached with honesty and authenticity that may be at odds with the motivations for joining a rescue charity (Shae, 2019): Appendix 2 suggests that nobody joined the charity to develop other people. Critics of Servant Leadership argue that it reduces authority (Whiteside, 2021), and in the rescue-services authority may be an important factor (West and Murphy, 2016).

Authentic Leadership

Leading with purpose and vision, rather than by imposing goals and rules, and being transparent about your motivation is the hallmark of an authentic leader and can be taught through reflection and self-awareness (Waite et al., 2014). Not adapting leadership to others' needs, holding steadfast in beliefs and vision can be a strong footing for others to draw inspiration and follow (Dascal, 2016) but critics argue that values should be open to debate and democracy rather than the standpoint of a single person (Gardiner, 2011) and that authenticity can lead to the creation of a "fake self" (Chamorro-Premuzic, 2020). Authenticity, however, is a key message in charity (Tallet, 2019) and an emotionally intelligent, credible leader can inspire positivity in volunteers (Dascal, 2016).

Comparison of practice against theory

Transformational leadership, whereby the Chair or Trustee team champion values, is evident in WMSAR (Appendix 3.4), but it is vulnerable to time constraints of volunteering (Doci et al., 2020) and can stall when there is a change of elected or appointed leader (Kotter, 2012). Leaders behaving as inspiring role models is important (Warrilow, 2012), and seems to be happening (Appendix 3.8), but Warrilow (2012) recognises the burden on leaders who must challenge, interact, and drive a team, acting as a personal guide to many individuals to push the organisational vision, which can lead to burnout (Matthews, 2019) and which Appendix 4 suggests is occurring.

Transformational leaders must also be aware of over-burdening their team towards burnout (Chen et al., 2018), and should encourage team-working to avoid this (Warrilow, 2012).

LMX approaches are evident in WMSAR (Appendix 3.7/8), with personal relationships between leaders and members being key to achieving the consistent standards necessary for audit. However, LMX is highly time consuming (Haynie et al., 2018) and very difficult to sustain for those "Super Volunteers" (Einhold and Yung, 2018) who require more leadership time. Furthermore, focussing on a few personal relationships is to the detriment of the wider team (Gordon, 2021; Appendix 3.6). A multi-layered leadership could facilitate LMX across the charity, but only if it was structured enough to increase "perceived organisational support" (Martens, 2017) to all.

Servant Leadership has been shown to promote goodwill and motivation towards volunteering (Erdurmazli, 2019), and increase the effort of volunteers (Einold and Yung, 2018), but in a wholly voluntary organisation the leaders themselves may be left questioning "effort vs benefit" (West and

Murphy, 2016) of their time donation vs their personal reward. Servant leaders require a “deep understanding of the basic motives of volunteering” (Erdurmazli, 2019); something that the charity does not teach, but perhaps a characteristic that should inform direct recruitment of Trustees with separate volunteering motivations from the operational team (Shae, 2019).

Authentic leaders are essential in charity, where accountability and transparency are law and the public have a right to scrutinize (Weymouth, 2019). Facilitating a vision-driven organisation where members are inspired by leaders’ core values and integrity gives better results than focussing on finances (NonProfitTimes, 2017), but there exists a continual trust-building-balance in an organisation with short tenures of leadership and frequent turnover of leaders (Centre for Creative Leadership, 2021). The concept of authenticity is one bestowed on a leader by others, and not themselves (Goffee and Jones, 2005) and so it is through a combination of these management styles that it may be best for WMSAR’s leaders to earn that recognition from their members.

Conclusion

WMSAR’s leaders require awareness that they directly affect the decision of other volunteers to leave the charity and must lead with retention in mind (Smith, 2017).

Transformational Leaders may not always be available for election as WMSAR has a small membership and leadership does not always match with members’ motivations (Appendix 2). However, there is leadership experience in most “Super Volunteers” (Einolf and Yung, 2018) and the charity strategy could take advantage of this if a clear vision and values are published. Championing these values through stories and teamwork is key to group understanding (Groysberg et al., 2018).

Personal relationships are important in maintaining a perception of organisational support, and reducing attrition (Martens, 2017). Leaders should foster relationships in a trickle-down manner — reducing the burden on leaders of dedicating time to large numbers of individuals — as a mentoring arrangement (Volgistics, 2021). This may also help to reduce any resentment from observation of higher leaders engaging in smaller social circles (Furnes et al., 2015) and encourage teamwork, empowerment, and trust (Weymouth, 2019).

Servant Leadership is recognised as greatly beneficial to retention of volunteers as it facilitates personal development, autonomy, and satisfaction (Oostelander, 2014, Smith, 2017). But motivations of Servant Leaders are distinct from those which attract people to rescue (Shae, 2019) and the charity may struggle to maintain a volunteer who is willing to serve at the detriment of their own development (Matteson and Irving, 2005) if recruitment is based on operational interests alone.

The Trustees must recognise good next-leaders (Einolf and Yung, 2018: p14) and consider authentic, respected members who communicate well, inspire and encourage others to reach their full potential

(Mohan, 2020), but whose personal values can be met through leadership roles, and this may require candidates to be reflective and honest in their self-examination (Goffee and Jones, 2005).

The charity should encourage leadership training and reflection for existing and emerging leaders, which is a neglected but highly important aspect of voluntary charity management.

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Appendices

Appendix 1 – Hours and number of attendance by charity member at events, 3yrs.

Member Ref	Hours' Attendance	Attended Events
WM93	2045	371
WM96	1779	335
WM36	1701	349
WM69	1697	332
WM66	1661	379
WM32	1615	326
WM71	1234	227
WM13	1214	244
WM52	1193	236
WM88	1134	223
WM86	1109	204
WM43	1087	223
WM94	1005	172
WM17	989	174
WM03	951	163
WM18	910	167
WM11	850	193
WM16	847	182
WM30	834	154
WM20	803	217
WM12	791	159
WM61	784	142
WM57	776	170
WM74	692	104
WM83	692	135
WM23	686	140
WM24	679	130
WM84	615	106
WM73	585	130
WM28	536	113
WM95	484	95
WM22	456	97
WM98 Driver	419	84
WM31	392	103
WM02	372	70

WM06	327	56
WM97	326	69
WM91	310	76
WM35	304	49
WM34	302	64
WM27	290	51
WM92	204	43
WM70	173	37
	149	30
WM101 Driver	141	31
WM76	135	33
WM26	114	27
WM100 Driver	109	24
WM111	104	26
WM121	82	17
WM05	82	17
WM106	76	21
WM119	68	17
WM72	51	14
Paramedic - On Call	44	10
WM117	43	10
WM114	42	11
WM125 Driver	41	8
WM21	29	10
WM115	29	6
WM103 Driver	27	9
WM118	24	6

Appendix 2

The author recognises limitations of the Appendices 2-4 are the method of distribution via WhatsApp, the willingness of volunteers to respond to the author as Chairman, trust in anonymity of the responses, and the bias of questions.

Anonymous Survey to WMSAR members – Why did you join a SAR Charity?

- A way to help people and utilise skills I have gained over the years. Also helps keep me up to date too.
- I was looking for something useful to do after retirement, and wanting to use skills developed in my previous work and leisure interests, whilst helping other people
- It was an opportunity to use my many years water experience to do something helpful for the community and wanted to expand the scope of my volunteering.

- I felt something was missing from my life, needed a hobby and this seemed worthy, exciting and potentially fulfilling.
- Believe it is a vital service to several communities across our patch
- I was part of West Mercia Police years ago, and since leaving to follow a career in engineering I missed doing something worthwhile with my time. I wanted to do something for the community, be a good role model for my children and be part of a team again. I also really enjoy the challenge, being outside, navigation, comms, and an excuse to spend money on outdoor gear!
- Make use of my outdoor skills for doing more than just walking the dog or up hills. If I can help others with either sharing my skills or directly helping others then so much the better.
- Two reasons. Firstly, I was missing helping less fortunate people and combining my love of the outdoors. Secondly, my mental state was poor and I needed something to throw myself into. For that opportunity I will be forever grateful.
- I was looking to volunteer and do something that I was also interested in and thought I could be good at.
- At the time I low feeling pretty low, and it's been great to be part of the team, and feel like I'm doing something worthwhile.
- To utilise my experiences and qualifications and give back to the community. To be part of the SAR Brotherhood. To belong to something that made a difference
- To help people and to bond with new colleagues
- I joined after meeting some team members when my local town flooded. I found the willingness to help others and their friendship regardless of how rubbish the situation was, was amazing. I wanted to be part of a team like that and to give back to my community.
- From being involved in scouting for a very long time after giving that a break unwanted to join and continue giving something back

Appendix 3

Anonymous survey to WMSAR members – Culture and Direction

3.1 Do you have a favourite event from your time with WMSAR? If so, what was it, and why does it stick in your memory? It can be a callout, training, event or social...

- I enjoyed the large public search for [redacted], where the team really galvanised and worked well together under intense public scrutiny. We knuckled down and got on with the job, feeling like everyone lifted their game and was working with a sense of pride in the uniform.
- Water trg outside Shrewsbury. Trg in the day then a pub meal and social evening, camped out then on the water the next day
- As weird as it might sound, the water safety patrols in Shrewsbury over the festive period.
- Search around Malvern area. Young boy with learning difficulties been missing all day after playing hide and seek. Big crew turn out and quite a long search. Eventually after a few

sightings we adopted a corralling technique to try and flush him out which worked. He was fine and had enjoyed hiding from all the people in uniforms (fire).

- Good teams, great result.
- It’s the combination of all the activities and feeling of being a member of a useful team
- Callout and live find
- I really enjoyed X’s trainings at at his place last month. It was a good mix of core competencies, but with some fun team building stuff built in, which was great fun. It’s important that we enjoy what we do to keep people engaged and it was very well thought out.
- Any of the live finds and being able to reunite a family.
- Water training
- I really enjoyed the most recent whole team event at Minsterley. A change from the norm and great to hear my team mates laughing and joking whilst problem solving.
- My first find - reminded me why we do it. The team support I was shown afterwards was incredible. It’ll haunt me for life but it’s meant I can stay above some of the politics which happens in any team and remind myself why the charity is there.
- Having a good outcome to a search
- The Shrewsbury river festival days were always good great way to get the team out there showing what we do on the river and great to chat to the public as well .
- doing the recovery at Tenbury during the floods
- The first Mercian Challenger training stood out. Great fun, good team spirit, competitive and it wasn’t raining
- Working together well as a team, with other teams with just the common goal of finding a missing person!
- Nav training. It’s a great team building activity and good to talk to team members.
- Tenbury Floods.... it brought everything together that we had trained for in the water team and tested our abilities. Reinforced the level we operated at the time. Team work/ support, professionalism was top notch
- It would have to be my first search. Finding the person alive and being able to help and get them home was one of the best feeling I think I have ever had.

3.2 Are you proud to be a team member? If so, why in particular?

- Yes, we provide a vital service to a strained emergency service
- Yes. See above
- I’m still very new to WMSAR, so I feel I haven’t contributed enough to be proud yet. I’ve been on half a dozen callouts, which have been good. I’m proud to give my time to the charity and the activities we do, I feel I have more to do to earn my place yet.
- Yes. We all have a common goal when somebody is in crisis
- Yes...because we provide a service to the vulnerable
- Yes - the hard work pays off

- We're a good group and I class a lot as friends
- Yes I'm very proud to be part of this team knowing that when your struggling no matter what someone in the team will always have time for you.
- yes . when i look back to when i started we have come such a long way. we are up there with the best.
- Yes, although perhaps feeling less motivated than when I joined.
- INCREDIBLY proud. I love doing this! We find people, we save lives and bring closure at the worst time in many people's lives. When at a CALLOUT everyone works together and we get it done and that is brilliant!
- Yes- it's a great way to give back to the community. I'm proud to be a member of the team because I am proud of the team and what WMSAR stands for. It's great to be part of the team.
- Yes. Sense of belonging to something that matters to the community
- Yes. Getting someone back to the loved ones or just bring closure to a family.

3.3 Do you think that the charity currently has strong values? And if so, what do you think they are? (e.g. openness, trust...)

- Yes. Integrity and trust between the misper, police and the team. We hold secrets and work to protect the vulnerable. We are proud to be team members.
- Yes, misper respect and privacy
- Externally, yes – i.e. what we do/stand for, but less so amongst the team internally. If i had to select one, it would be team cohesion, everyone is willing to assist, advise and support.
- A strong duty of care, however this needs to be balanced with common sense when needed.
- Yes in terms of offering a service to the public but could be clearer direction and openness internally
- It is mixed and there are a chosen few
- I think so. The team is very highly thought of by the public, which proves the ethos of the team. Trust is important, and it's clear on callouts that there is a great deal of trust between team members.
- Yes the core value of helping somebody or their family is still the same -but some people within the team need to remember why they signed up in the fist place. Trust within the team has weakened recently.
- Yes...tha value of the service provided
- I believe that we do. Covid has tested the charities resolve.
- We could be more open and believe we are moving in that direction.
- Trust, supporting, commitment, honesty, concern for others, integrity
- Not sure, which probably means no
- The values are set out for us strong comradeship
- Yes. we are a proper charity. not a business in disguise .

- Being caring and committed to finding the misper
- No but I don't think we need them! Don't over complicated this charity. Stick to basics.
- Yes. Empathy, trust, professionalism, transparency. I am newish and from day 1 felt a part of the team. You put such trust into people who are sometimes strangers on the day of call out, because you know what the team stands for and that everyone who is part of the team values those core values of the charity.
- At our core its a community and team based value of supporting each other. We like many are struggling with consistency coming out of lockdown etc
- Yes I do. Everyone is welcoming and more than welcome to give advice and answer questions. As a new member I feel this is a great way to progress.

3.4 Do you think that the leaders of the charity/team show these values?

- Yes, the leaders of the charity are all volunteering so they show these values in the worth that they bring to the team. They are all trustworthy. They are all open and tend to listen to concerns.
- 100%
- Yes.
- Yes but could be more regularly communicated to wider team.
- On the whole yes, and I am encouraged by the recent changes in personnel and the new keenness to get organised for the future
- There are some good leaders but it isn’t balanced and people are leaving or considering leaving
- Yes, I have a lot of time for the leaders and senior members, and they command a great deal of respect which speaks for itself.
- Mostly
- Externally yes...internally no so much
- I believe they do
- Leading by example is so important, and I think the management team generally do. I’m a bit out of the loop currently though.
- Yes they sometimes do more often than not
- Some do however I think many do not anymore.
- yes
- Not really sure what’s going on, but I’m out of touch.
- More recently I think changes have been made which appear to show the OMT as more open which is a good thing.
- Yes- certainly, the leaders are so approachable and are always there to advise and support. Everyone in the team is.
- Yes from the inside... I'm not sure it's seen like that from the wider team
- Yes. No matter who I ask a question to they have the time to help.

3.5 What do you think the vision of the charity is? (Looking for your personal interpretation, not what's written on the website)

- To be a sustainable resource, available when the public/police need us. Trying to achieve that through fundraising, and retention of members.
- To be more efficient and effective on call outs
- To continue to provide the SAR capability across the region; look to innovate and use new technology and equipment to remain relevant and adaptable. Be the 'one stop shop' for the police for their SAR needs by building stronger relations with them, FRS etc through continued demonstrating our capability and skills.
- To help find vulnerable people in times of need.
- To offer a professional standard service with a team of well trained volunteers that can grow and develop with the necessary funding
- No unified answer - my view it’s save life and find the lost
- To have a highly trained and dedicated core team, who are reliable and can be called on to bring people home in a timely and respectful manner.
- To be the best SAR team in the UK. To be able to be looked up at by other teams in SAR with the best kit and equipment. To reunite families with loved ones.
- Not necessarily sure I see a vision further than running the service
- We provide a valuable service to the vulnerable, by fundraising to train and deploy a search team.
- We also provide educational support for our community
- To provide well trained and extremely competent support to emergency services in times of need.
- To continue doing what we do best helping people
- I think the vision is to always do as best of job as we can in the circumstances given and that we will always help others .
- to continue to grow and improve
- Not sure
- Work with emergency services to find and help people in danger. Be that Missing Person, Flood or other emergency.
- To keep being there to support the public services in supporting the community and raising awareness.
- To support the community the best way we can
- Generally helping the local community. Wether that’s bringing a missing person home or bringing closure to a family or getting people to a place of safety in the event of flooding.

3.6 Would you recommend any changes to the leadership/management to reach that vision?

- I'd like to see better integration and understanding between the operations and fundraising sides of the charity, and more dialogue on needs/wants for both.
- Install a hierarchy. And an organagram
- Continue to forge strong/better links with emergency services to demonstrate our capability. Invite them to training sessions/joint training? Look to have a stronger presence in Worcestershire / Herefordshire?
- People management is always hard but don't hold grudges. Engage in dialogue rather than snipe away behind the scenes. It's a shame we have lost people recently and they clearly felt they could not comfortably raise these issues.
- Better integration of fundraising with the needs of the charity through closer engagement with the OMT and contributing to the business plan
- Stop giving certain individuals all the training eg why are SRTs on Quads when some searches need both. More effort on training water team on medical when the live finds are on land - it is sad when you see kit sat there because a few individuals are the chosen ones
- More team building would be good, to help at those times when we need each other.
- Ignore LR.
- Be more inclusive to all members...I see a lot of members falling off the radar and getting forgotten about. This drives the constant need for recruitment
- I think we are in a good place to grow from. Recent changes will invigorate that journey.
- No
- It’s a new management team we need to give them a chance
- As far as the vision goes I think everyone is like minded
- Not sure what the vision is. Wondering whether it might be good to merge with SARA.
- For it to be made clear who does what. Who is the CMT? Who is the OMT? What are their roles.
- None.
- Consistency- but an appreciation of the extra time and work commitments holding a leadership position has on individuals
- I think the current management do an amazing job keeping us all trained and motivated.

3.7 Have you ever raised an issue with a leader or manager? If yes, were you listened to? And was it acted upon?

- Yes
- N/A
- Yes, many. Yes, listened to and acted on.
- n/a
- Yes and partially acted upon.
- Yes and no -
- I haven’t had to, no.

- Yes. Yes.
- No
- Yes and yes
- Yes - I was being pressured into taking more responsibility than I felt I could manage in the long term despite politely declining. Raised with chair/land search lead. Quiet word had in background, pressure gone.
- No I haven’t
- I have sometimes thought about but often kept my thoughts to myself on different subjects
- yes. i was listened to. but i don't think it was acted upon. i complained to matt w over the way marc passmore spoke to and treated me and john goode.
- Never raised a formal complaint. I’ve raised other requests which haven’t been dealt with, but I guess everyone’s busy.
- Not sure if it would be worth having a formal system for requests and give them a ticket number.
- Yes and yes... never had an issue approaching leadership and being listened to
- No.

3.8 Do you have faith in the current leaders of the charity as a group (Trustees, OMT, CMT)? If NOT, what would you change and why? (Please don't single-out any individuals for criticism here, it's more a study of culture and behaviour).

- Yes
- Yes. We've had lots of changes recently, but everyone seems skilled and keen to make a difference and keep the charity going strongly.
- Yes - no concerns.
- Yes. They are all volunteers.
- I am optimistic about the new management team.
- However it is not clear who is part of the CMT.
- Balance out the skills and think about retention. Put more effort into retention and also nobody should get any courses in their first year.
- I do, I think the image presented is that of a single vision with a good team of people to realise it.
- Yes -but better trust will take time to develop further. Small group training session more frequently may help
- As a member of all of the above I cannot comment I feel. I'm happy.
- I do worry that the number of experienced members is thinning out, relying heavily on a few. I feel a little powerless to help more although I’d like to.
- Keep us better informed more quickly
- There needs to be less clickey groups there are always the favourites in any organisation like this however everyone should be more included there should be more social events

throughout the year as well to get to know people better and also the training program should be reverted back to more how it used to be with training every other week or so and that the intake of new people should go back to how it was before as there are now loads of people in the team I have not meat how can you work with people that you do not know.

- yes .
- Previously I would have said 100% yes and felt lucky to have the leaders. Currently not sure. Just haven't seen people for a while.
- Yes, they work well. People will always moan, ignore them
- Yes (I have faith in the leaders)
- Yes 100% top guys all of then cmt and omt
- Absolutely. Any I have chatted to always have the time to talk and answer any questions I have.

3.9 Is there anything you'd like to change about the Charity's culture or direction, and if so, what and how?

- More social get togethers and team bonding needed as Covid has created a lot of barriers to group working. A lot of people have pulled away and hunkered down. We need to get back that spirit of team working.
- Just more engagement with the green group for ideas, we have a vast mix of experience in different disciplines that can take the charity forward. The young blood will be the future.
- It's good that we are starting to open up opportunities through EOIs - whilst the final decision will take into account attendance, skills, experience and time in the team, the fact that everyone feels they have a route to specialisation will help make people feel involved and part of the team. (Team cohesion)
- More sharing of what the management does please.
- Continue the openness and take more time to deal with any issues face to face rather than using media like text and email.
- Consider all the team not just a few who get to have all the shiny toys. Look after the Land Search teams better as that is a core activity
- No, I've loved my short time with the team. More team building exercises would be great for the reasons mentioned above.
- Better communication between the leaders and the crew to keep crew more up to date with what is happening within the charity.
- Difficult as the operational work and basses seem to be mor north faced, but need more south of the region inclusivity
- I think bringing in more external training will give the troops more drive and enthusiasm.
- Very literally - it all seems to be moving northwards in direction.
- To forward information immediately from any meetings that go on

- Stop with all the favouritism and work more to gel better as a team going forward this year. I will have been doing this for six years and I can say in the last two and half I have seen a down turn which needs to be turned around as to how that is to be done I’m not sure .
- no
- See above
- None
- Nothing at all.
- Still very Bridgnorth/ Shropshire based
- Being new, I don’t know enough to have an opinion on this.

Appendix 4

Anonymous survey to WMSAR Management Team - Do you feel your leadership role has enhanced or detracted from your volunteering experience?

- On the plus side having a greater understanding of how the team functions has been great. But it’s time consuming.
- Occasionally it can be negative due to some members misguided views on what the extra responsibility entails.
- I think it has enhanced my experience overall.
- Originally enhanced and still does... but the additional time and work commitments of the role are a lot more than the wider team can appreciate. Personal circumstances change, work/life and there has to be a personal balance to remain and sustain being a volunteer operationally and for the charity. Being able to standdown/ back/ sabbatical front these positions will enable leaders to remain in team and share the wealth of knowledge and experience.
- Detracted from my original urge to feel I've added value and fulfilled something, since I made a choice to take on more managerial tasks at the detriment of operational tasks. I've had to seek validation and satisfaction vicariously on many occasions, as a member of the team rather than being involved in an operation or event. This secondary validation isn't as fulfilling but does come with some sense of reward and pride. Conversely, the experience of volunteering as a leader has given me a great deal of experience in that field and a better understanding of how to communicate with others where the motivation for them to continue working is purely emotional.
- Detracted to some extent. Constantly having to try to motivate was difficult as was seeing people who failed to carry out their role be allowed to continue without getting challenged.
- Overall Enhanced it. A leadership role gives an insight into how the charity should on paper run, verses how it runs on the ground.
- Enhanced - I feel that not only can I now just find and save people in danger, but I can now shape the way that the charity does this and try and get this done in a more efficient manner. What does detract from this is the politics, grudges and that people (particularly in the management team) lose sight of why they joined and why we actually go searching, to help people.

Incorporating Ocean-Borne Debris Information into Search Object Location Distributions

Lawrence D Stone
Chief Scientist
Metron
USA
Email stone@metsci.com

J Van Gurley
CEO
Metron
USA
gurley@metsci.com

John R Frost
Office of Search and Rescue
US Coast Guard
USA
John.R.Frost@uscg.mil

Abstract

This paper presents a method for incorporating information from waterborne debris that has been recovered at a known time and place into the object location distribution. The method involves calculating a likelihood function which can be combined with the prior distribution on the location of a lost object, such as a ship or aircraft lost at sea, to produce, in a Bayesian fashion, a posterior distribution that reduces uncertainty in the location of the loss. When the search operation involves a person or vessel adrift at sea, incorporating debris information in this fashion will allow the search planner to produce better predictions for the location of the search object at times of future searches and enable more effective deployment of search assets. Use of this method will save time, money, and lives.

KEY WORDS: *Maritime Search and Rescue*, *Ocean-Borne Debris, Maritime Loss, Debris Drift, Object Location Distribution, Bayesian, Posterior Distribution*

Introduction

Despite the considerable communications technology and capabilities available to most vessels and aircraft today, there are still incidents where they are lost at sea without anyone receiving a distress call from them. In such situations, the realization that the craft is missing may not occur until it becomes overdue at its destination. This will delay the initiation of search efforts. Once a search is undertaken, the first objects found are likely to be floating debris that was left on the surface and drifted away from the accident site due to winds and currents. When this happens, the first question is, “Where could this debris have come from?” to be quickly followed by, “Within the ‘possibility area,’ which locations are more likely and which are less likely to have been the source of this debris?” Accident investigators may want to locate the sunken wreckage, especially if recording devices were being carried. If there is the possibility of survivors (which often follow drift trajectories different from debris), search and rescue (SAR) authorities will want to know the location of the incident so they can develop better estimates of where survivors adrift will most likely be located when SAR assets can be on scene searching.

The predominate method of incorporating debris information into an object location distribution involves performing a “reverse drift” on pieces of debris from the time and place of recovery to the time of the distress. In the US Coast Guard’s Search and Rescue Optimal Planning System (SAROPS), Kratzke et al (2010), this requires the user to specify uncertainties in the wind and ocean current estimates and run the SAROPS drift system backward in time using the negative of the estimated wind and current velocities. There are several difficulties with this method. First, reverse drift models are not well tested and validated. Second, the resulting reverse drift location distributions tend to have very large uncertainties (spreads) if the debris is found more than one or two days after the time of the distress. As a result, the reverse drift distribution often provides very little information about the location of the distress. Finally, a better way to incorporate this information is to apply Bayesian inference – a widely used method for adjusting prior probability estimates based on subsequently discovered evidence.

In the first section below, we show two examples of reverse drift distributions produced for the Air France Flight 447 search in 2009 -2011. Debris from the AF447 search was first recovered six days after the plane crashed into the ocean. The first example shows the large uncertainties produced in the reverse drift distribution from these debris using the SAROPS method. This estimate provided very little additional information about the location of the aircraft wreckage. The second example shows a reverse drift distribution that did not correctly account for wind and current uncertainties and that produced a very poor estimate which resulted in a year of wasted search effort.

In the second section below, we describe our proposed method of incorporating debris information. It uses forward drift predictions and constructs the likelihood function for this information which allows us to combine this information in a Bayesian fashion with the prior distribution to produce a posterior distribution and reduce the uncertainty in the object location. We note that our forward drift methodology is essentially a Bayesian version of the BAKTRAK method presented in Breivik et al. (2012). We illustrate the power of the forward drift method by showing how it was used to incorporate information from a piece of debris from the Malaysian Airlines Flight MH370 crash found on Reunion Island. In this example we see that this debris information reduced the uncertainty in the object location distribution even though it was found more than a year after the loss. The third section compares the reverse drift and forward drift methods of incorporating debris information.

The MH370 example involves search for stationary target. However, in the fourth section below, we show how this forward-drift method can be applied to search objects that are moving such as survivors adrift in a lifeboat. In the fifth, we show how to apply the forward drift method when the time of loss or distress is uncertain.

Reverse Drift Examples

In the early morning hours of June 1, 2009, Air France Flight AF447 from Rio de Janeiro to Paris disappeared during stormy weather over the Atlantic with 228 passengers and crew aboard. Figure 1 shows the last known position (LKP) of AF447.

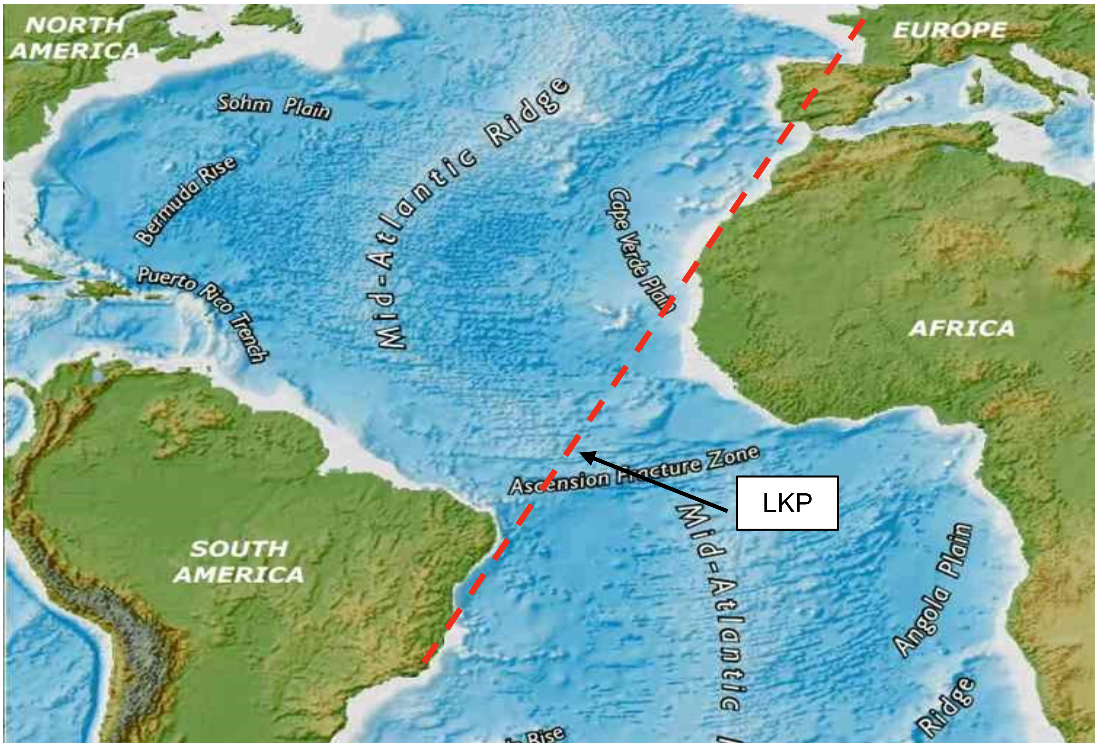


Figure 1. Last known position (LKP) for AF447, 2.98°N, 30.59°W

At dawn a surface search for survivors and wreckage began. On June 6 the first bodies and floating debris were found 38 nautical miles (nm) north of the LKP. The French Bureau of Enquiries and Analysis (BEA) took charge of the search and estimated that the plane must have crashed within 40 nm of the LKP as shown in Figure 2.

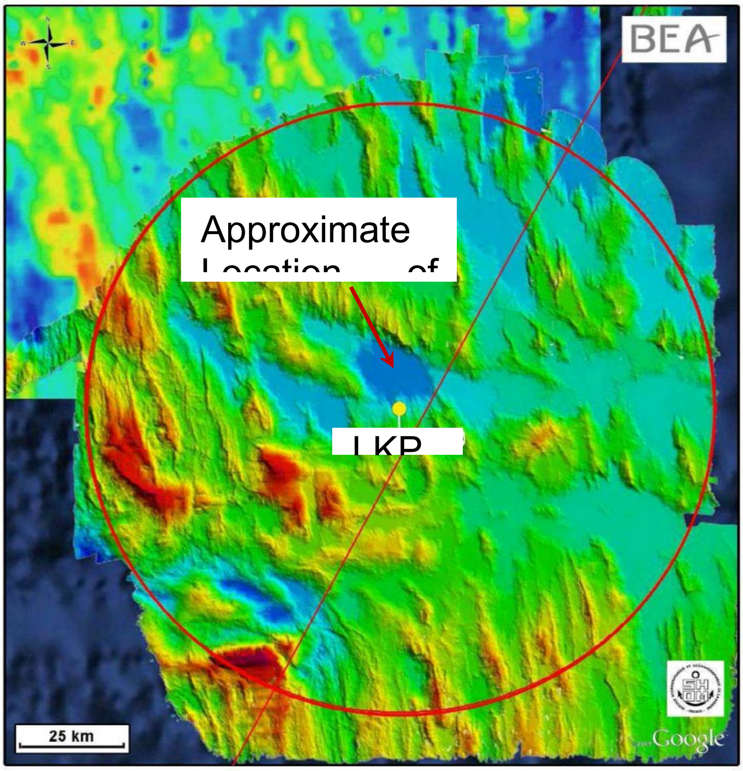


Figure 2. 40 nm circle about LKP

An intense acoustic search was performed to detect the underwater locator beacons (ULB) attached to the flight data recorder and cockpit voice recorder. This search was unsuccessful. The following year an intensive sonar search was performed based on a faulty reverse drift analysis by a group of oceanographers called the drift group. This search was also unsuccessful. In 2010, after two years of unsuccessful search, Metron was tasked by the BEA to compute a probability map for the location of the wreck using all available information including unsuccessful search as well as recovered bodies and debris. On April 8, 2011, BEA issued the following statement

> *This [Metron] study, published on the BEA website 1, indicated a strong possibility for the discovery of the wreckage near the center of the [40 nm] Circle. It was in this area that it was in fact dis e week of exploration.*
>
> —— Trodec (2011).

SAROPS Reverse Drift for AF447 Distribution.

One piece of information that Metron used to construct its probability map was the set of positions and times at which 33 bodies were recovered from 6-10 June 2009. The positions of these bodies were drifted back to the time of crash using the best wind and current estimates available to us for the time and place of the crash. We used the SAROPS reverse drift methodology with our best estimate of the uncertainty in the wind and current estimates. The result of this was a distribution with an extremely large spread extending far beyond the 40 nm circle as shown in Figure 3. This was not very helpful in locating the wreck.

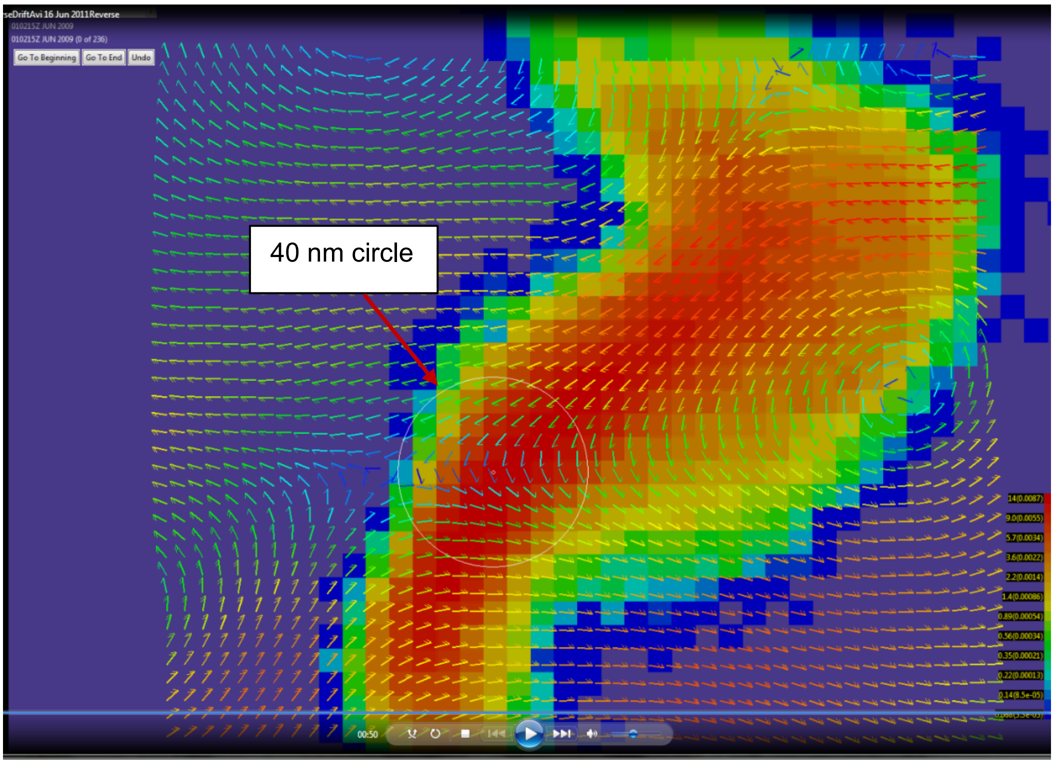


Figure 3. Reverse drift distribution. The 40 nm circle is shown as a thin yellow line. Vectors indicate the estimated direction of the surface currents at the time of the crash

Drift Group's Reverse Drift Distribution

Over the winter of 2009-10, the BEA assembled a team of distinguished oceanographers (the drift group) and tasked them to produce a reverse drift distribution for the location of wreck. They used data from Argo floats, NOAA's Atlantic Oceanographic and Meteorological Laboratory surface drifters, and fishing buoys drifting in the area at the time of crash to inform their current models. Using these models, they performed a reverse drift of the positions of the recovered bodies and debris found on June 6 and 7 back to the time of the crash. They took the average of the "most consistent" predictions to obtain the rectangle shown in Figure *4* which they claimed was a 95% containment region for the location of the wreck. The search in the summer of 2010 was based on this rectangle and was unsuccessful. There are a number of methodological errors in this approach, but the main ones are (1) the failure to properly incorporate the uncertainty in their predictions into their estimate of the location of the wreck and (2) the removal of predictions that were "inconsistent" with the majority of the predictions.

The drift group's prediction also violated one of the cardinal rules of search planning – namely use all available information when forming estimates of the search object's possible/probable locations during the next search. In the fall of 2010, the BEA asked Metron to produce a probability map for the location of the wreck over the winter of 2010-11 using all available information. This effort produced the probability map that the led to finding the wreck within days of resuming the search in the spring of 2011.

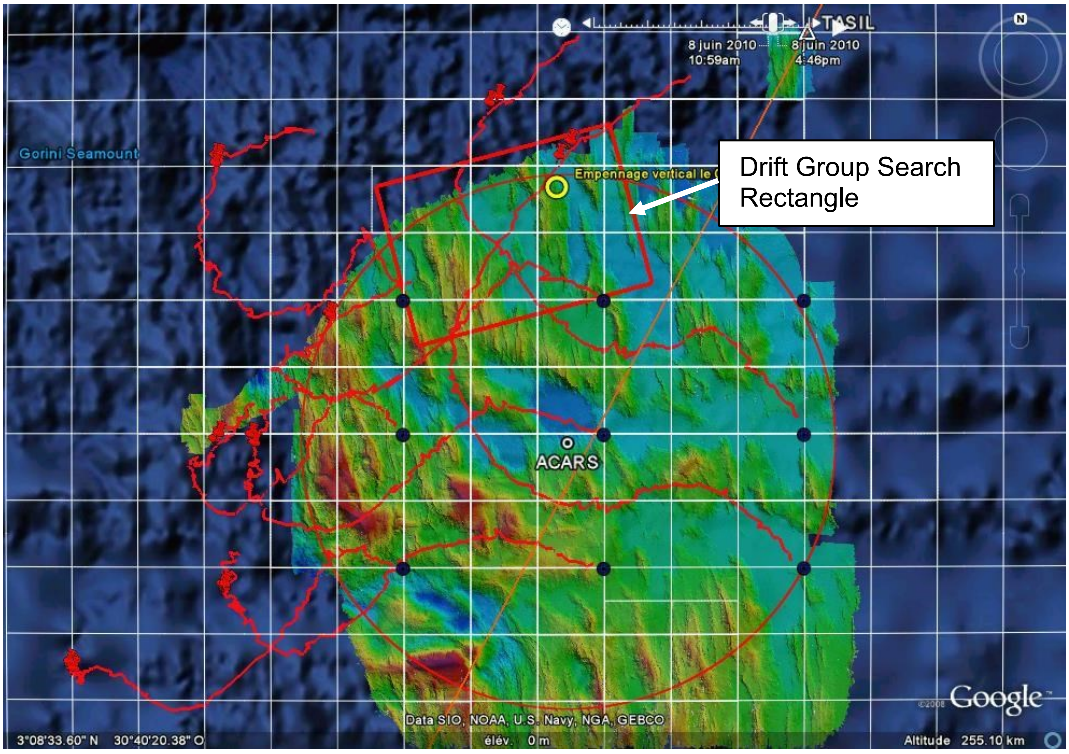


Figure 4. The red rectangle is the 95% containment region estimated by the drift group. The circle is the 40 nm circle. The "wiggly" lines are the paths of 8 data buoys placed inside the 40 nm circle on June 3, 2010 and allowed to drift for 6 days. The wildly different paths of these buoys illustrate the complexity of the ocean currents in the search area.

Forward Drift Method

This section describes a Bayesian method for incorporating debris information into the probability distribution for a search object whether it is stationary or moving.

Likelihood Function for Recovered Debris

Suppose a vessel or aircraft is presumed sunk in the ocean, and we are uncertain about its location. Suppose that a piece of floating debris is recovered at a location y at time T after the loss and that it is determined that the debris came from this craft. If we have a model for debris movement in the vicinity of the loss over the time during which the piece of debris floated on the water, we can use this model to compute a likelihood function for the location of the loss. This likelihood function can be combined with the prior distribution on the location of the loss to compute a posterior distribution for the loss location. In this Bayesian fashion, the posterior will incorporate the information from the debris recovery into the estimate of the location of the loss. As more debris is found, this process can be iterated to refine the posterior probability estimate of the source location.

Computing the Likelihood Function. For convenience, we impose a grid of cells on the ocean area of interest indexed by $j = 1,\ldots,J.$ Let $p(j) \geq 0$ be the prior (before incorporation of the debris information) probability of the vessel being located in cell $j.$ We assume that

$$\sum_{j=1}^{J} p(j) = 1.$$

The observation (y,T) is the location and time (after loss) of the recovery of the debris. The likelihood function L for this observation is defined as follows.

$$L\big((y,T) \mid j\big) = \Pr\{\text{Debris floated to position } y \text{ over time } T \mid \text{ it originated in cell } j\}.$$

Note that the observation (y,T) is fixed or known. The cell j is variable or unknown. As a result, the likelihood L is a function of $j.$ This function need not be a probability distribution on the set of cells $j = 1,\ldots,J,$ i.e., it may not sum to 1. It gives the relative likelihood of the various candidate cells being the origin of the piece of debris.

Using a model of winds and currents plus leeway assumptions, one can perform the following set of experiments to estimate the likelihood function in . Designate a region R around the point $y.$ The size of this region is somewhat arbitrary but it should be large enough to capture a reasonable sample of the drift particles used to estimate $L.$ For each cell j in the prior distribution, generate a large number N of initial points in that cell and drift them for time T using independent draws from the statistics of the ocean currents and winds to produce N drift paths. Calculate the number n_j of paths that enter R over time T . Then

$$L\big((y,T) \mid j\big) \approx \frac{n_j}{N}$$

is an estimate of $L\big((y,T) \mid j\big)$ for $j = 1,\ldots,J.$

Computing the posterior. Using Bayes rule, it is now straight-forward to compute the posterior distribution for the location of the loss. It is given by

$$\tilde{p}(j) = \frac{L\big((y,T) \mid j\big)\, p(j)}{\sum_{j'=1}^{J} L\big((y,T) \mid j'\big)\, p(j')} \quad \text{for } j = 1,\ldots,J.$$

MH370 Example

This example is taken from a Metron technical paper by Gurley and Stone (2015) written shortly after the first piece of debris, a flaperon from the wing of MH370 (Figure 5), was found on Reunion Island (Figure 6) off the East Coast of Africa more than a year after the crash. The paper developed the forward-drift likelihood function method of incorporating debris information and applied it to the MH 370 flaperon found on Reunion Island. At the time the paper was written, the authors did not have detailed information about the prior probability distribution being used by the Australian Air Transport Safety Board (ATSB) to plan their search, so they relied on public statements and press releases to approximate this distribution. They also had to rely on a publicly available and somewhat coarse-grained model for ocean currents, and they did not account for the possible effects of wind (leeway) on the flaperon. Nonetheless, the example and analysis summarized below show that incorporating this debris information produced a significant shift to the north of the location distribution for the MH370 crash. Details of the analysis are given in Gurley and Stone (2015).

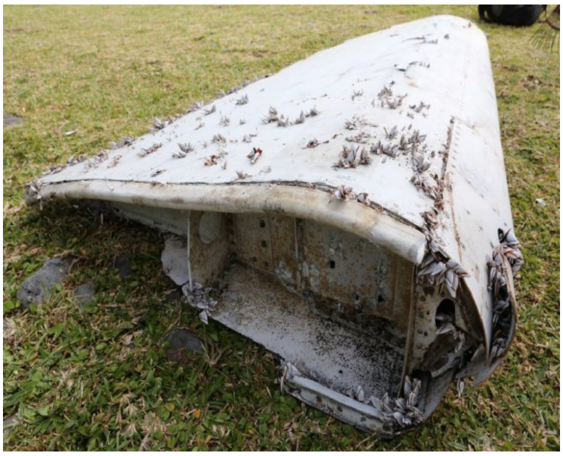


Figure 5. Flaperon found on Reunion Island 29 July 2015

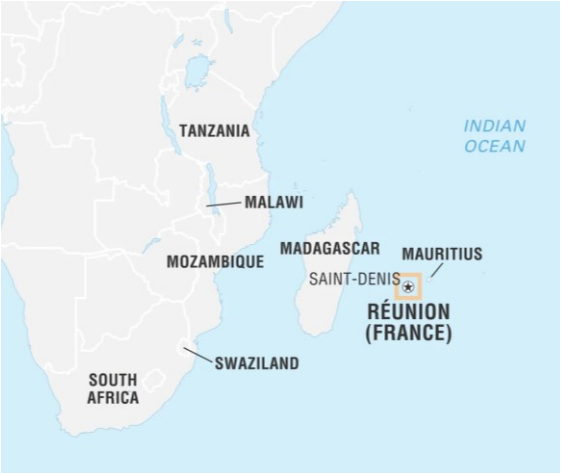


Figure 6. Reunion Island

An extensive analysis (ATSB (2016) and Davey et al (2016)) performed by the Australian Defence Science and Technology (DST) Group in 2016 used more detailed modelling of ocean currents, a model for the leeway of the flaperon, and the forward-drift likelihood method of the paper to produce a similar analysis using the flaperon and other debris recovered from MH370. The overall conclusion was the same. The probability distribution for the location of MH370 was shifted to the North as a result of incorporating the debris information.

Forward-drift likelihood example

Gurley and Stone demonstrated the forward-drift likelihood method by generating a 2-dimensional posterior probability map for the location of the MH370 that incorporated their best estimate of the prior probability distribution for MH370 based on public statements from senior ATSB officials directing the search operation. They computed a 2-dimensional likelihood function using the information from the recovery of the flaperon on Reunion Island and a general, long timescale, probabilistic debris transport model for the drift model for the debris.

Ocean drift simulation

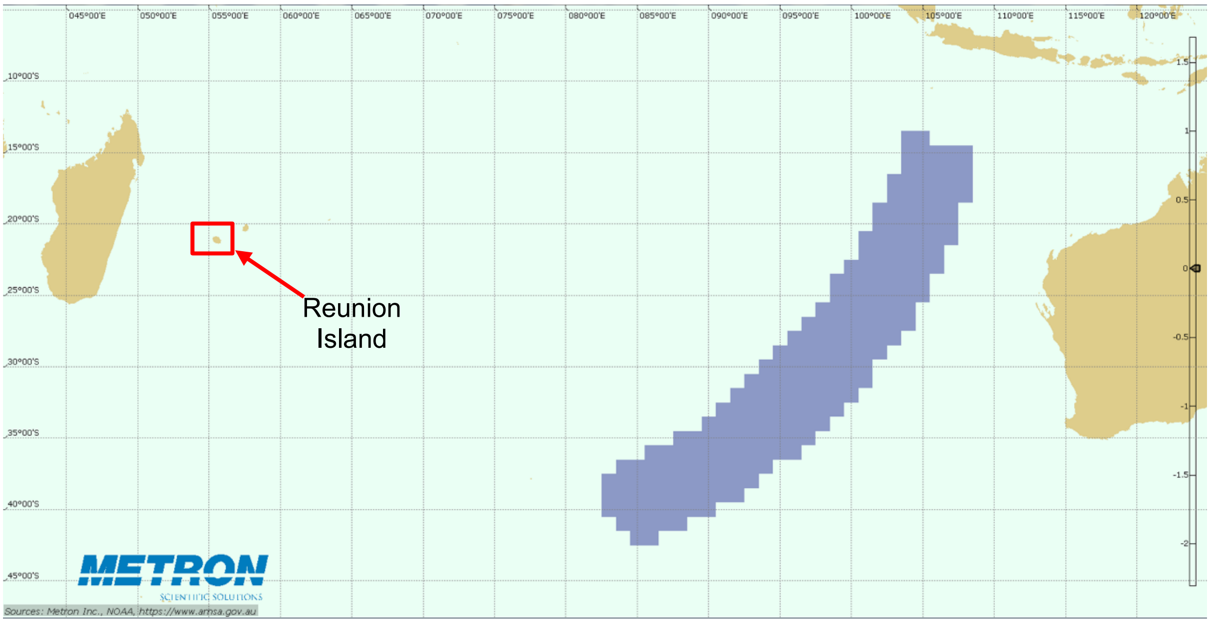
van Sebille et al (2012) used multiple decades of ocean drifter buoy trajectory data from the Global Drifter Program to generate a transport model that captures the observed dynamics of ocean circulation on global and regional scales. Their approach models ocean debris movement as a discrete-time Markov chain process where the transition matrix $\mathbf{T}$ represents the probability of debris movement from any grid cell to any other grid cell at each time step. Based on the ocean drifter buoy data, van Sebille empirically derived $\mathbf{T}$ for a global $1^{\circ} x\ 1^{\circ}$ grid at $\Delta t = 60$ days. To capture seasonal variability, van Sebille derived separate bimonthly values for $\mathbf{T}$ by analysing observations over 2-month windows throughout the year. Specifically, they estimated $\mathbf{T}_{\text{Jan-Feb}}, \mathbf{T}_{\text{Mar-Apr}}, \text{etc}$. From these transition matrices, the probability distribution of debris can be computed by iterating the equation

$$p_{t+60\text{ days}} = p_t \mathbf{T}_m \text{ where } m \text{ is the bi-month index corresponding to starting time } t$$

and p_t is the row vector of probabilities in cells for the location of the debris at day t.

There are several assumptions implicit in this approach. First, we assume that the ocean drifter buoy trajectory observations that are the basis of the transition matrices $\mathbf{T}_i$ adequately approximate the general movement of a debris field in the open ocean. No attempt is made to perform high-resolution modelling of separate wind and current forcing or leeway modelling to predict the resultant differential movement due to the different sizes of individual pieces of debris. van Sebille notes that while all the drifting buoys were deployed with drogues at 15m depth, approximately 52% lost their drogues during their reporting life. Therefore, the observation set is a random mix of objects impacted by wind and current forcing (buoys without drogues) and objects impacted by current forcing only (buoys with drogues). This closely approximates the mix of debris typically found at sea (van Sebille et al (2012)): some objects at the surface are subject to wind forcing and some are near-neutrally buoyant just below the surface not impacted by wind forcing. Second, the van Sebille model conserves mass. It assumes that all initial drift particles remain in circulation: all coasts are hard boundaries, so nothing washes ashore, and nothing sinks.

Under the limits described above, Gurley and Stone used this model to estimate gross debris drift patterns over a 480 day period starting in March 2014 varying the source location across the ATSB MH370 Wide Search Area region (MH370 (2014)). For their analysis, they considered the arc segment bounded by -15.3 $^{\text{o}}$ and -40 $^{\text{o}}$ to provide sufficient buffer both north and south for the prior distribution. The width of the region is $\pm$ 125nm normal to the arc at each point which is the maximum distance from the arc that ATSB considered across all their end-of-flight scenarios (see Table 1 of ATSB (2014)). These parameters define an annulus sector on the earth's surface. Since all the subsequent analysis was conducted on the $1^{\text{o}} x\ 1^{\text{o}}$ latitude/longitude grid used in the debris transport model, the final set of grid cells examined as possible source areas is the intersection of the regular $1^{\text{o}} x\ 1^{\text{o}}$ grid and the defined annulus sector. This yielded 213 candidate grid cells as shown in Figure 7.



Sources: Metron Inc., NOAA, https://www.amsa.gov.au

Figure 7. MH370 Wide Search Area grid cells (blue) used for candidate source locations

At simulation start, debris were uniformly distributed across a $3^{\text{o}} x\ 3^{\text{o}}$ box centered at each of the 213 candidate source cells. Debris movement was then drifted forward eight time-steps (480 days) starting in March 2014. Examples are shown in Figure 8.

Likelihood Function Estimation. To estimate the likelihood function $L\big((y,T)\,|\,j\big)$, they designated a sink region around y, and for each of the 213 candidate source cells, they accumulated all particles that arrived at y during any time step up to the end time T. Let $n(y,t,j)$ be the number of particles that arrived in the sink region at time t from source cell j for $j=1,\ldots,213.$ Following

$$L\big((y,T)\,|\,j\big) \approx \frac{1}{N}\sum_{t=0}^{T} n(y,t,j) \quad \text{for } j=1,\ldots,213.$$

Since the van Sebille model is mass conserving, all particles entering the sink region y are removed from the general population at the time step at which they enter the region. This prevents double counting during subsequent time steps. The sink region was modeled as a $3^{\circ} x\, 3^{\circ}$ box centered on Reunion Island (-21,56). The resulting estimate of $L((y,T)\mid j)$ is shown in Figure 9 for all 213 cells that comprise the MH370 source set.

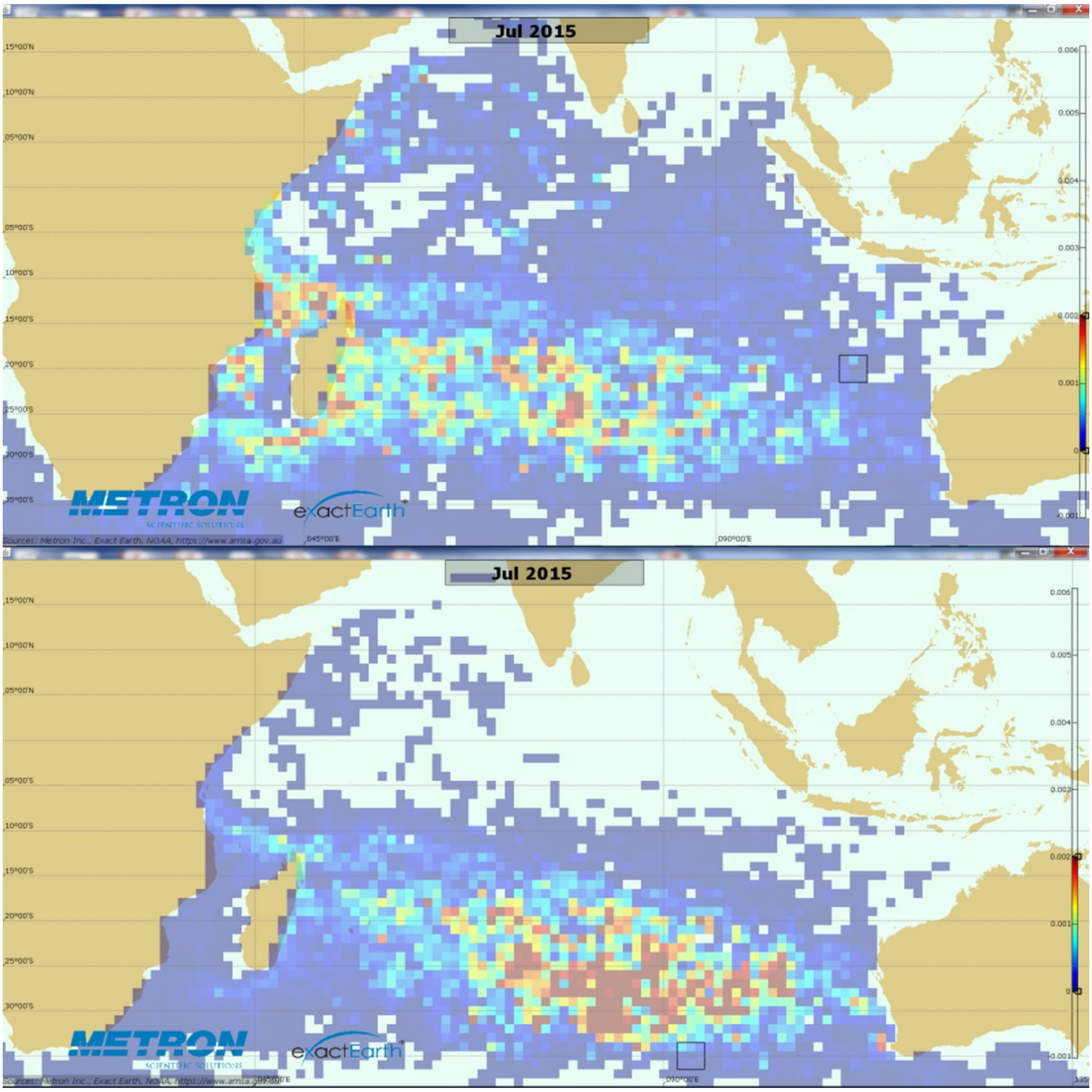


Figure 8.Probability distribution of debris after a 480-day drift simulation for sample northern (top) and southern (bottom) source regions within MH370 Wide Search Area zone. Source region for each is shown as a black box. Red is 0.002

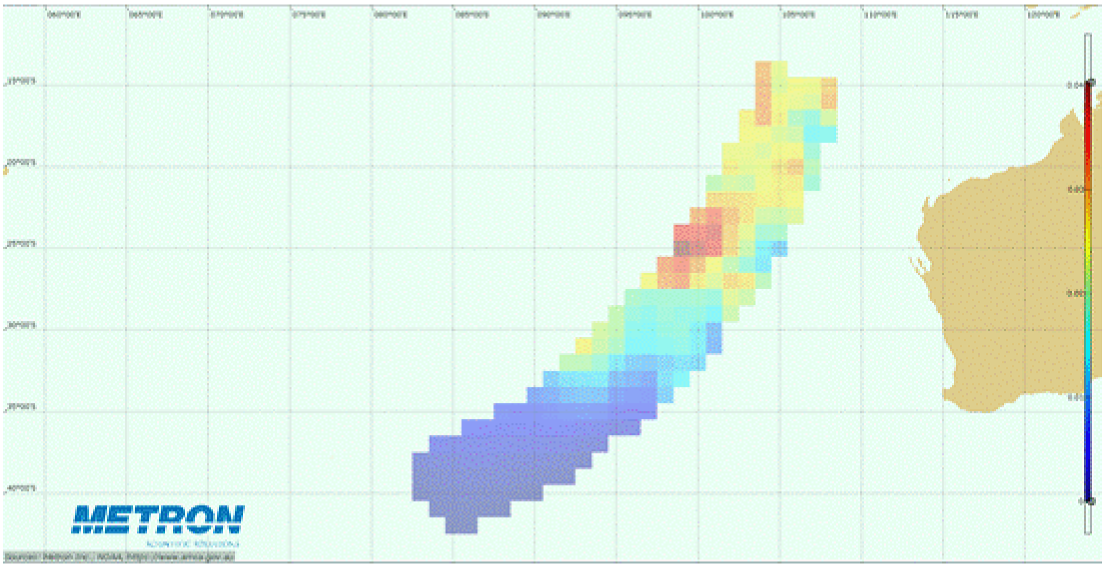


Figure 9. Estimate of likelihood function for the MH370 flaperon found on Reunion Island as a function of source region location. Red is 0.04.

To better understand the spatial distribution of relative values across all the possible source grids, we computed the ratio

$$\Lambda((y,T)\,|\,j) = L((y,T)\,|\,j) \,/\, \max_j L((y,T)\,|\,j)$$

We found that cells in the northern portion of the MH370 Wide Search Area are ~10 times more likely to be the source location than cells in the southern portion.

Prior and Posterior Distributions

Gurley and Stone then attempted to estimate the prior probability distribution in use by the MH370 search team (in 2015) based on the published ATSB reports and public statements from Australian officials. Their focused search zone had progressively shifted to the more southern areas of the Wide Area Search region over 2014-2015, and statements in 2015 from senior government officials describe a very high certainty that the MH370 impact zone was in the extreme southern portion of the Wide Area Search region.[1] Based on a review of the ATSB operational reports, the area they have concentrated on is roughly bounded by the latitudes -32° to -39°. While there isn't enough information in the available ATSB reports to explicitly calculate the prior probability distribution or to assess the source of

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[1] Australian Deputy Prime Minister was quoted in Wall Street Journal Article on 04 August 2015 saying that "The experts are telling us that there is a 97% possibility that it [MH370] is in that area [current search area] and if you move into a wider area there is just too much to be covered for a small chance of finding the aircraft."

ATSB's certainty in their assumptions, Gurley and Stone approximated the general shape of the prior probability distribution that is the basis for the ATSB planning.

The paper modeled the prior distribution on the location as a product of independent distributions on two components, distance normal to the arc centerline and distance along the arc centerline from -40°. The paper gave the first component a normal distribution and the second component a gamma distribution with $\alpha = 5.8, \beta = 1$. This gamma distribution has the desired properties of quickly going to zero immediately to the left (south) of the peak, concentrating about 95% of the probability in the region between -39 ^{o} and -32 ^{o} and retaining a more gradual tail to the right (north) of the peak. The normal component is modeled by a Gaussian distribution with mean 0 and $\sigma = 50 \text{ km } (27 \text{ nm})$. The resulting prior and posterior probability distributions are shown in Figures 10 and 11. The change in probability in each cell from Figure 10 to Figure 11, $\Delta p(j) = \tilde{p}(j) - p(j)$, is shown in Figure 12. The regions that have increased in probability are shown in red and those that have decreased are shown in blue. Figure 12 shows a clear shift of the posterior distribution to the north reflecting the effect of applying the debris likelihood function.

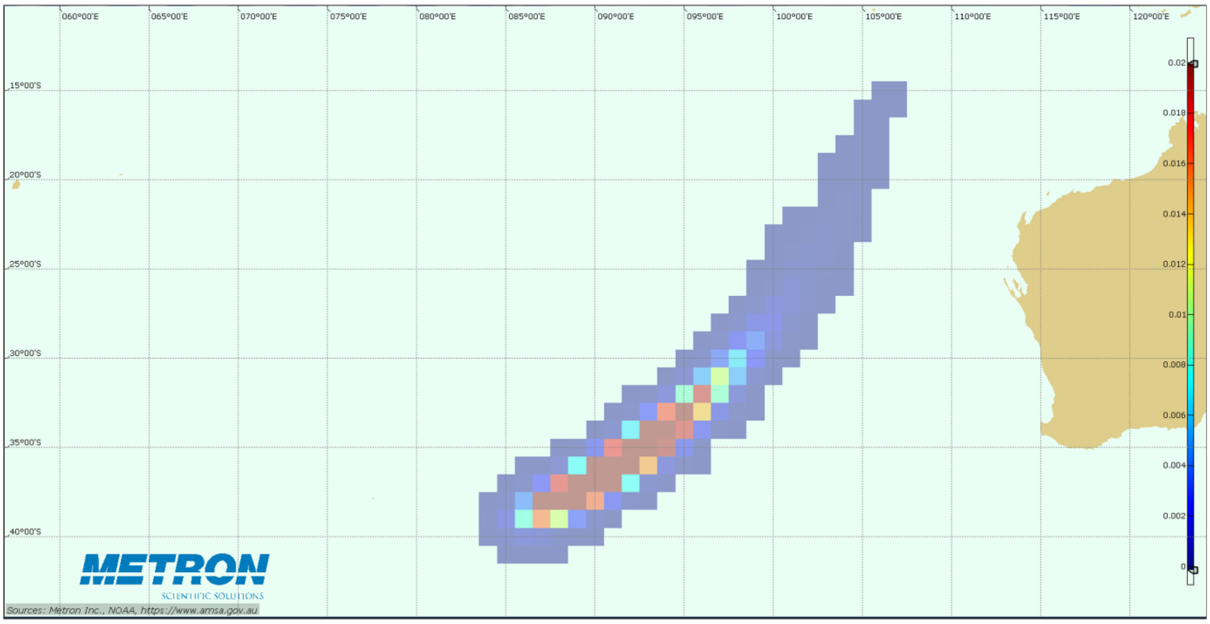
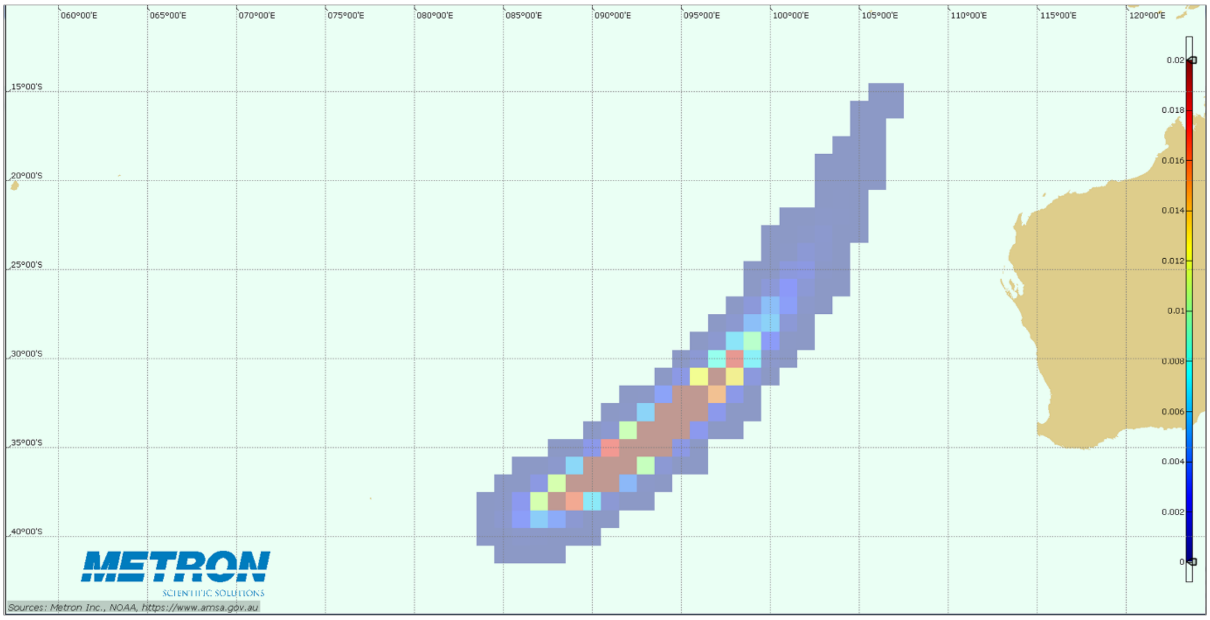
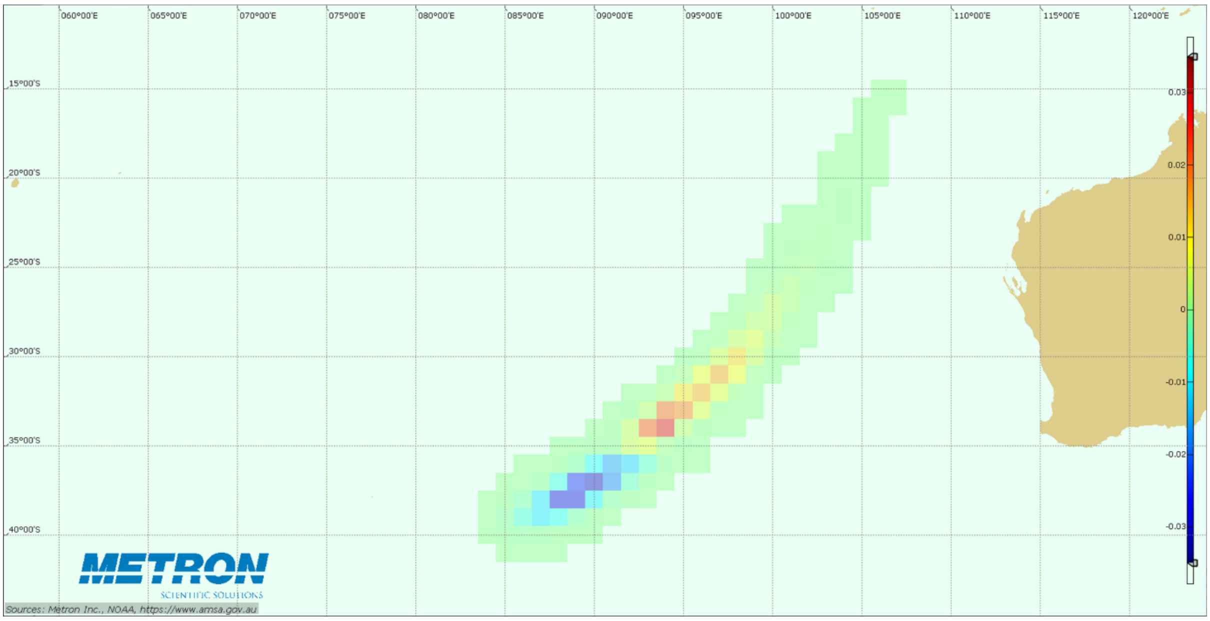


Figure 10. Bivariate prior probability distribution. Max scale (red) is 0.02.



Sources: Metron Inc., NOAA, https://www.amsa.gov.au

Figure 11. Posterior probability distribution. Max scale (red) is 0.02.



Sources: Metron Inc., NOAA, https://www.amsa.gov.au

Figure 12. Change in probability distribution of possible MH370 impact sites based on discovery of the flaperon on Reunion Island. Scale is +/- 0.035

Comparison of reverse drift and forward-drift likelihood methods

The contrast between the results of the SAROPS reverse-drift estimate for the location of AF447 based on the bodies found 6 to 10 days after the crash and the forward-drift likelihood method for incorporating information from the MH370 flaperon found on Reunion Island more than a year after the loss of MH370 is remarkable. Using reverse drift, the information from the bodies, found only 6 to 10 days after the AF447 crash, provided little helpful information for the location of AF447. By contrast, using the forward-drift likelihood method demonstrated the potential to provide significant information more than a year after the loss.

Moving Search Objects

The discussion so far has centered on the incorporating debris information into the location distribution for a stationary search object. In this section, we describe how to use the forward-drift likelihood method to incorporate debris information into distributions for moving search objects such as missing people or boats in the ocean.

For a moving search object, we begin with the object location distribution at the time of loss. Designate this as time $t = 0.$ Search for a moving object requires that one specify a (probabilistic) model for the movement of the search object over time, so that one can forecast the probability distribution for the object location at any time $t > 0.$ For the convenience of this discussion, we will divide time into discrete intervals so that $t = n$ refers to the $n\text{th}$ time interval, and we will treat the object as stationary during a time interval.

To incorporate debris information, one calculates the likelihood function using and above and incorporates it into the object location distribution at $t = 0$ using . One then applies the motion model to this distribution to obtain the updated distribution at any time $t > 0.$ If there has been unsuccessful search during time interval $t = n$, then one must compute the posterior at $t = n$ given this unsuccessful search before motion updating to times $t > n.$ If one is planning a search at time t , then one needs to use the object location distribution at that time updated for the debris information and unsuccessful search. This will yield more effective and efficient search plans.

Uncertain Distress or Loss Time

If the time of the distress or loss of the object is uncertain, then the calculation and application of the debris likelihood function in - is still straight-forward but more complicated. In place of the initial distribution on location in , we must specify a distribution on the time s and location j of the loss or distress. Let $s=1,\ldots,S$ be the possible loss times, the prior in becomes

$$\sum_{s=1}^{S}\sum_{j=1}^{J}p\left(j,s\right)=1.$$

The debris likelihood function in becomes

$$L\left((y,T)\,|\left(j,s\right)\right)=\Pr\left\{\text{Debris floated to position}\,y\text{ in time }T\,|\text{ it originated in cell}\,j\text{ at time}\,s\right\}.$$

The posterior distribution on the time and position of loss or distress in becomes

$$\tilde{p}(j,s)=\frac{L\left((y,T)\,|\left(j,s\right)\right)p(j,s)}{\sum_{s'=1}^{S}\sum_{j'=1}^{J}L\left((y,T)\,|\left(j',s'\right)\right)p(j',s')}\text{ for }j=1,\ldots,J\text{ and }s=1,\ldots,S.$$

Conclusion

This paper has presented a Bayesian forward-drift method of incorporating debris information into a search object location distribution. It compared this method to the reverse-drift method commonly used by SAROPS and other search and rescue planning programs. We showed by example that reverse drift can lead to a distribution with very large uncertainties which does not provide useful information on the object location. By contrast, we presented an example using the Bayesian forward-drift method that showed that even debris recovered more than a year after the loss can provide valuable location information. Finally, we discussed how to extend the forward-drift method to moving search objects and to search objects whose time of distress or loss is uncertain. The forward drift method needs to become the new standard for incorporating information from drifting debris.

About the authors

Lawrence D. Stone. Dr Stone joined Metron in 1986. He became Chief Operating Officer in 1990 and Chief Executive Officer in 2004. In 2010 he returned to primarily technical work as Chief Scientist. He was the major technical contributor to the U. S. Coast Guard's Search and Rescue Optimal Planning System (SAROPS) which went into operation in 2007. He is a co-author of the books, *Bayesian Multiple Target Tracking* and *Optimal Search for Moving Targets*. The Operations Research Society of America awarded the Lanchester Prize to Dr Stone's book, *Theory of Optimal Search*, as the best work in operations research in 1975.

In 1986, Dr Stone used Bayesian search methods to produce the probability maps used by the Columbus America Discovery Group to locate the *S.S. Central America* which sank in 1857, taking an estimated three tons of gold coins and bars to the ocean bottom one and one-half miles below. He headed the Metron team that used Bayesian methods to produce the probability maps that led to the location on April 3, 2011 of the wreckage of the AF447 flight which disappeared over the Atlantic in June of 2009. Recently Dr Stone used Bayesian methods to combine historical, topological, and geophysical information to find the lost (since the end of the 16th century) Spanish gold city of Logroño de los Caballeros in the jungles of Ecuador.

In 1999 Dr. Stone was elected to the National Academy of Engineering. He is a fellow of the Institute for Operations Research and Management Science. In 2008 he was awarded the J. Steinhardt Prize for outstanding contributions to Military Operations Research by the Military Applications Society.

J. Van Gurley. Mr. Gurley joined Metron in 2013 and became President and Chief Executive Officer in 2019. Prior to his current role, Mr. Gurley served as Chief Operating Officer, Senior Vice President, and Senior Manager at Metron where he led a number of rapid innovation projects in predictive analytics, data fusion, and automated mission planning for the Federal Aviation Administration, U.S. Navy, and Defense Advanced Research Projects Agency.

Before joining Metron, Mr. Gurley completed a 26-year career in the United States Navy rising to the rank of Captain while serving as a submarine warfare officer and naval meteorology and oceanography specialist. During his navy career, he led several strategy and innovation efforts that transitioned new technologies into fleet operations. These included development and execution of a complete restructuring of the naval oceanography community's undersea warfare support programs coupled with accelerated fielding of major new technologies in unmanned ocean sensing, ocean and acoustic modeling, and mission planning. While serving as the Military Deputy/Executive Assistant for the Oceanographer of the Navy in the Pentagon, he served on the leadership team that developed the U.S. Navy's first strategy and policy for climate change.

Mr. Gurley has degrees in physics, engineering, and management from the Massachusetts Institute of Technology, Woods Hole Oceanographic Institute, and University of Florida. His research work was honored with the Ruth and Paul Fye award for excellence by the Woods Hole Oceanographic Institute Applied Ocean Physics and Engineering Department. In addition, he was the U.S. Navy's 2003 Federal Executive Fellow with the Massachusetts Institute of Technology Security Studies Program.

John R. Frost. Mr. Frost joined the U.S. Coast Guard in 1971 and retired from active duty with the rank of Commander in 1994. During this time, he served aboard the USCG Cutter Taney, at Rescue Coordination Center, San Juan, PR, the Operations Analysis Branch of USCG Atlantic Area (lead analyst for Computer Assisted Search Planning), obtained an MS in Computer Science from the US Naval Postgraduate School, served as assistant Chief of Search and Rescue for USCG Atlantic Area, Commanding Officer of USCG Operations Computer Center, and Special Projects Officer (SAR) at USCG Research and Development Center. After this he joined Soza & Co., developing portions of the USCG SAR Addendum and portions of the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual. In 2004 Mr. Frost returned to USCG employment as a civil servant with the Office of Search and Rescue at USCG headquarters in Washington, DC. He is the principal architect of the USCG's Search and Rescue Optimal Planning System (SAROPS) and continues to serve as the Program Manager for SAROPS.

Abbreviations

AF	Air France
ATSB	Air Transport Safety Board
BEA	Bureau of Enquiries and Analyses
DST	Defense Science and Technology
LKP	Last Known Point
MH	Malaysian Airlines
nm	nautical miles
SAROPS	Search and Rescue Optimal Planning System

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Part 1 – The Search Intelligence Process Using Artificial Intelligence

Christopher S. Young
Contra Costa County Sheriff's Search & Rescue Team
Chairman Bay Area Search and Rescue Council (BASARC)
Email csy1492@comcast.net

Dr. Franz Kurfess
Computer Science and Software Engineer Department
California Polytechnic State University
San Luis Obispo, CA, USA

Gary Bloom
Retired Software Company Executive
San Mateo County Sheriff's Search & Rescue Team

Abstract

Intelligence is a process by which certain types of information/data are aquired or requested by those directing a missing person incident. The process continues by rallying teams of resources to collect, process and exploit, analyze and produce useful information that can then be disseminated and integrated into actionable plans.

Traditionally the collection, processing, exploitation, analysis, and production has been done by hand on paper and sorted by experienced search leaders and training of the human brain. However, what if this work could be done by computers and artificial intelligence? This is the hypothesis we are exploring through a privately funded university effort. The "Artificial Intelligence for Search and Rescue" is a project with goals to use AI and related computational methods and tools to support Search and Rescue (SAR) missions. This project is a collaboration with California Polytechnic State University (Cal Poly) Computer Science and Software Engineer Department Dr. Franz Kurfess, undergraduate and graduate students in alliance with alumnus Gary Bloom and Christopher Young both experienced search and rescue incident managers. The project began in the summer of 2021 through privately funded research, senior projects, and class projects.

This paper is Part 1 and will describe the initial work included the collecting and consolidating the pertinent mechanisms for storing and processing data and the research of the potential artificial intelligence options. Part 2 will describe the final product after lab/field testing and refinements.

KEY WORDS: *Intelligence Gathering, Missing Person, Interviewing.*

Introduction

The Search for Missing Persons:

When someone is reported missing, generally to a law enforcement agency, a set of tactics and processes begin to locate the subject. With the receipt of the first call and response to a missing person incident, details start to emerge about the missing subject. Initial information is vague and unclear but as more investigational intelligence becomes available a clearer picture becomes apparent which allows searchers and search managers to accomplish their respective duties to find the subject. However, there is still the need to look closer at the subject's attributes for more detail and nuances that make up the sum of their experiences and connections to others that make them who they are. Further, there is more data and information developed from the active search effort. The processing of all this data has traditional been done by hand and on paper that eventually gets analyzed and processed by a human brain into something actionable.

What is Intelligence:

This paper is a natural follow up to the 2018 Syrotuck Symposium presentation and subsequent journal article "The Search Intelligent Process" by Young (2018). This was followed up by the publication of Young's (2022) book *Intelligent Search – Managing the Intelligence Process in the Search for Missing Persons.* In these documents intelligence is described as a process and can be thought of as the means by which certain types of information are acquired or requested, collected, analyzed and disseminated, and as the way in which certain types of actions are conceived, conducted and/or executed.

Graphically the process looks like Figure 1:

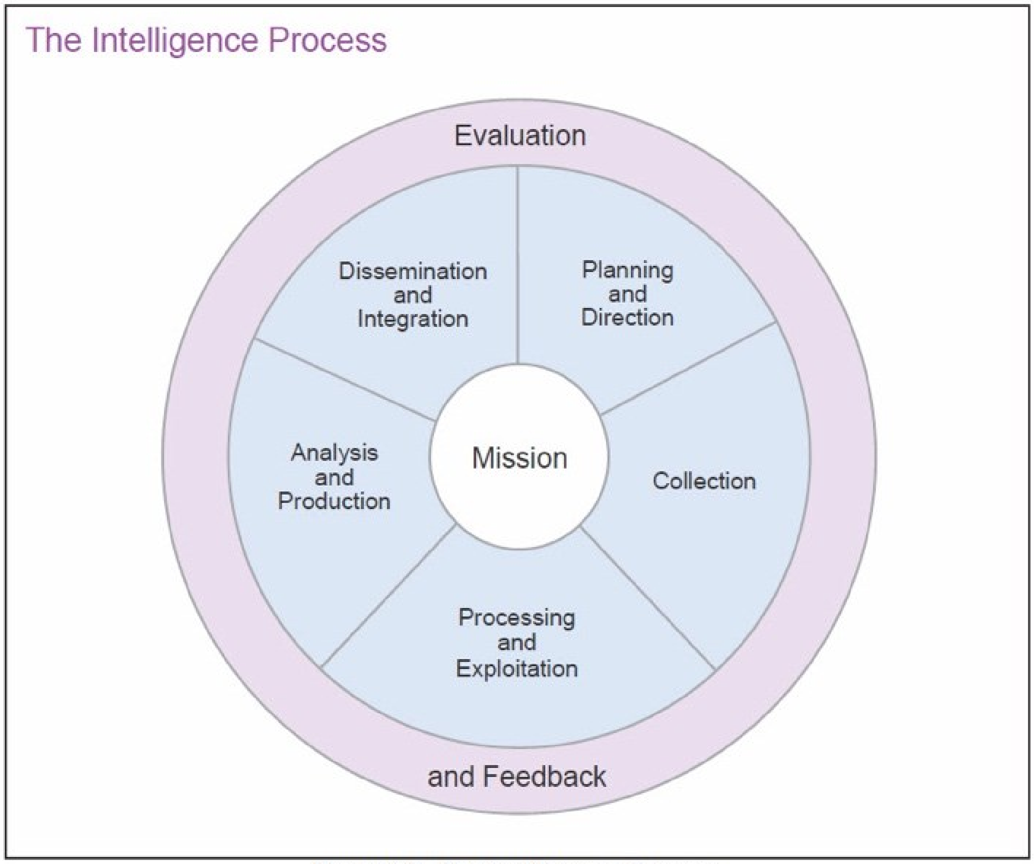

Figure I-3. The Intelligence Process

Figure 1: The Intelligence Process Source: (Joint Chiefs of Staff, 2013)

Defining each stage of the process from Young (2022)

Planning and Direction: the determination of intelligence requirements, development of appropriate intelligence architecture, preparation of a collection plan, issuance of orders and requests to information collection agencies. This may also include sets of established checklists and questionnaires for recurring events and missing person incidents (MPI).

Collection: those activities related to the active acquisition of data [information] required to satisfy the requirements specified in the collection strategy.

Processing and Exploitation: raw collected data is converted into forms that can be readily used by commanders, decision makers at all levels, intelligence analysts and other consumers.

Analysis and Production: all available processed information is integrated, evaluated, analyzed, and interpreted to create products that will satisfy the end user. The analysis would also include filtering out redundant information as well as false positives or negatives. Intelligence products can be presented in many forms including oral presentations, hard copy publications, or electronic media.

Dissemination and Integration: intelligence is delivered to and used by the consumer and used to make decisions and take action.

Evaluation and Feedback: occur continuously throughout the intelligence process and as an assessment of the intelligence process.

Further there are the analogies of **Tactical intelligence, Strategic intelligence, and Operational intelligence** defined as:

Tactical intelligence is focused on support of the operations at the tactical level and includes field searchers. Briefings are delivered to teams prior to leaving on assignment and include descriptions of the missing subject, items to look for, potential hazards, and other information that would aid the field searcher in identifying and locating the missing subject. This is classified as **Searching Data**. The teams are debriefed at the end of their assignment to elicit additional information for analysis and communication through the reporting chain.

Tactical intelligence can vary in its intensity based on the environment the missing person is in. If we are looking for an 80-year-old male missing in a wilderness environment the amount of data necessary may be minimal. It would be expected that there is only one 80-year-old male and a complete description or even a photograph of the subject is not necessary to send searchers out in the field. However, if we are looking for the same 80-year-old male in an urban retirement community, there could be several subjects that will need be sorted out by physical description and photograph.

Strategic intelligence is concerned with broad issues such as the number and type of resources to apply to the search effort. Such intelligence may be scientific (e.g., weather forecasts), technical, tactical, or diplomatic (e.g., pressures from the family, local politics, or other authorities having jurisdiction). But these changes are analyzed in combination with known facts about the area in question, such as geography or demographics, which may be related to safety issues as well as statistical lost-person behavior. In search management, this is referred to as more long-term value as **planning data**.

Operational intelligence is focused on support or denial of data at the operational level. In search management, this means managing clues and information as they become available and applying that information to affirm or refute the various scenarios being developed. This is the function of the **Clue Unit Leader**, sometimes referred to as the “Clue Meister” or “Clue Frog”—that is, the person to “jump on it” and take action.

The Paper Version of Data Collection

Throughout the law enforcement and search and rescue communities in the United States the standard for management of any emergency incident, including missing persons comes from the National Incident Management System (NIMS) guidelines under The Federal Emergency Management Agency (FEMA) which dictates the use of the Incident Command System (ICS).

The Incident Command System has developed standard forms that are used in most missing person incidents. In addition, there are search and rescue specific forms (SAR 1##) developed in the early 1990's by the (San Francisco) Bay Area Search and Rescue Council (BASARC) (Young & James, 1995) and have been widely adopted throughout California, the United States, Canada, and other parts of the world. Most importantly these data collection methods have been field tested, work well, and are easily trainable to less experienced management staff.

Further, the Missing Person Questionnaire (MPQ) is considered the most valuable source of information to paint a picture of who is the missing subject, the circumstances of their disappearance, and the best source in determining what the subject might do in a particular situation (e.g.: weather turns bad, night fall, rugged terrain).

For a list of all the forms used to collect data during a missing person incident both ICS and SAR 1##, see **Appendix A**

The Human Model of Processing, Exploitation, Analysis, and Production of Intelligence

Consider the initial collection of data from a traditional paper Missing Person Questionnaire (MPQ):

> Question: "Can he dress himself?"
> Response: "I have to lay out his clothes for him and help him with his socks."

This could be construed to be an innocent and innocuous response. However, in context of a missing person incident, the experienced human interviewer would recognize that there is more data to be collected and would follow up with:

> Follow up question: "Why does he need help with his socks?"
> Possible response: "He can't bend over to reach his feet."

Again, another innocuous response, but can further be explored by another follow up question:

> "Why does he have trouble reaching his feet?"
> Possible responses could be:
>
> 1. "He has a physical back/spinal movement issue limiting movement and/or is painful."
> 2. "He is overweight making it difficult to reach his feet."

3. "He has cognitive issues related to dementia/Alzheimer's."

Each of these final responses creates further human brain processing and analysis. An example of the further exploitation of the spinal issue would be:

1. "Is the limited spinal movement related to a chronic or acute back condition?" (Analysis: if this is chronic due to a disease what other limitations are there? If this is acute, due to an accident, where are they in the healing process?)
2. "Is the pain and limited motion relieved with medication and/or physical therapy/exercise?" (Analysis: what is the medication, side effects, potential overdose/underdose problems that could occur? What happens after several hours if they don't take their medications?)
3. "Does this condition limit their mobility?" (Analysis: how far can they physically travel by foot? Can they sit is a vehicle for only a limited time without having to stop and stretch?)
4. "Does this condition limit their survivability?" (Analysis: what other limitations are they experiencing that will limit their ability to stand up if they fall? Do they need a cane or walker (also related to mobility)?)

Based on the further tangent[1] questioning and analysis the human brain would surmise that there is a lot of intelligence to be compiled into actionable products to be used by the searchers in the field and the planners in the command post.

The Components of Artificial Intelligence

The research regarding Artificial Intelligence, started with the five basic components of learning, reasoning, problem solving, perception, and language understanding (CaseGuard, 2022). CaseGuard defines these components as:

Learning

As with human intelligence, the first step is the learning stage. There will be a trial-and-error process making mistakes and gradually learning the rules and techniques that are needed to effectively handle a task. In the context of artificial intelligence, the learning process requires the memorization of individual items including different solutions to problems, vocabulary, and foreign languages, among others. Through this learning process, programs that utilize artificial intelligence are able to keep notes of all actions or moves that led to positive results, allowing the program to leverage this knowledge within its data should similar problems arise in the future.

Reasoning

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[1] With every question there is a response. Responses to the original question will trigger an additional related question. Again, depending on the response, this may lead into a specific direction or set up a different line of questioning. These related questions are referred to as tangent questions.

Mental reasoning is something that has been limited to the human mind throughout history. Artificial intelligence centers on software programs that are able to draw conclusions and inferences from a situation, without the need for human interference, whether inductive and deductive reasoning. To this point, the use of inductive reasoning has allowed computer programmers and software developers to create products and systems that achieve consistent results when faced with a particular problem or issue.

Problem-solving

The creation of computer software programs and systems that solve problems in a manner similar to that of human beings and is one of the most essential components in the development of AI. AI's problem-solving skill is based on the application and manipulation of data, where the solution needs to be x. Conversely, in advanced applications, problem-solving techniques can include the development of efficient algorithms, performing root cause analysis with the goal of discovering a desirable solution, and heuristics.

Perception

In comparisons to the function of the human mind, the way in which individuals perceive the world around them is critical to the way they solve problems in their respective lives. AI perception is achieved through the utilization of different sense-organs, whether they be real or artificial. Human perception is extremely complicated. It can prove to be extremely challenging for AI programs to perceive certain inputs and information. A self-driving car is a classic example of perception of the outside world in order to function safely.

Language understanding

The understanding of language is the last component that makes up AI. Language understanding in AI can be defined as a system of signs having meaning using standard conventions (Copeland, 2023). Most AI programs and systems are developed within the English-speaking world and understand the English language. Through this language understanding, software developers can ensure that computer programs are able to efficiently execute their respective functions and operations.

Using the application of these components, AI systems can work effectively without the need for human inputs, as software programs that make use of artificial intelligence are able to govern themselves in conjunction with the codes or rules that are provided to them by software engineers and developers.

Literature Review:

The contexts related to individuals reported missing is complex and involve many factors. Factors include the various attributes of the missing subject including but not limited to age, the physical and mental health as well as physical appearance. The literature review focuses on the attitudes (data), applying one or more methods (tools) to extract the data, and then analyzing the information collected using one of several approaches (AI) to produce actionable intelligence. All the literature review expresses the goal of improving the outcome of the missing person incident. The literature can be consolidated into one of the following

- Focused on technologies in facial recognition.
- Looking at narrow demographics (E.g.: Missing adults with dementia, children with autism unaccompanied immigrating minors in Europe).
- Websites and applications dedicated to locating missing persons.

Facial Recognition:

Some published articles discuss the use of artificial intelligence ability to use biometric-based technology that mathematically maps a particular person's or individuals facial features and stores all that data as a face print. Face recognition models in these systems look for a match of the missing subject in the database. If a match is found it will be notified to the authorities who have jurisdiction for follow up investigation (Pawar, et.al, 2021), (Michalitsi-Psarrou, et.al, 2020), (Solaiman, et.al., 2022). Facial recognition technologies have gone so far as to allow developers to apply for United States patents for the deep learning technology (United States Patent No. US 10,163,042 B2, 2018).as well as develop mobile phone applications (Pawar, et.al., 2022).

Demographics

One published study discusses the use of machine learning methods to infer the reasons a person may go missing to assist law enforcement (Pierzchala, et.al., 2020(2)). Another study sought to identify individual and environmental factors that might predict where an older adult reported missing would be found (Ruiz-Rizzo, et.al., 2022). The latter study stated "…identified the individual factors that predict whether a missing older adult will be found, using a supervised machine learning model based on ensembles. The present findings suggest that there are intrinsic and extrinsic factors at play, all of which can influence the outcome prediction of older adults."

Websites and applications

A study published in 2021 *SaRNet: A Dataset for Deep Learning Assisted Search and Rescue with Satellite* Imagery (Thoreau & Wilson, 2021), looks at high resolution satellite imagery with dramatically improved resolution for humanitarian relief and Search and Rescue (SAR). The proposal uses a novel remote sensing object detection dataset for deep learning assisted SAR.

Closely aligned with our research

Most of the publications reviewed were not focused or aligned with our research and project goals. However, an older study *Data Mining of Missing Persons Data* (Blackmore, et.al., 2005), presented the results of analysis to evaluate the effectiveness of data mining techniques to predict the outcome for missing persons cases. A rule-based system was used to derive augmentations to supplement the missing person incident manager's intuition. The results indicate that rule-based systems can effectively identify variables for prediction. Another article *Knowledge representation for missing persons investigations* (Taylor & Reilly, 2017), looked at knowledge collections in missing person investigations and applying situation calculus to provide a "more relevant than an expert systems approach that would typically suggest a particular given action". This decision support approach aims to provide a set of relevant actions from which the officers or search leaders concerned in a missing persons case might choose or might combine as appropriate.

And still another article *Machine Learning-Based Method for Recommendation of Missing Person's "Search Level"* (Pierzchala, et.al, 2020), presented the use of various algorithm methods, decision trees, random forests, naïve Bayesian classifier multi-layer perceptron, and support vector machine to model and classify search levels to support decision-making problems concerning the actions of the Police (in this case in Poland) in the search of missing persons.

Discussion

The "Artificial Intelligence for Search and Rescue" is a project with goals to use AI and related computational methods to support Search and Rescue (SAR) missions. The project was developed in collaboration with California Polytechnic State University (Cal Poly) Computer Science and Software Engineer Department Dr. Franz Kurfess, undergraduate and graduate students in alliance with alumnus Gary Bloom and Christopher Young both experienced search and rescue incident managers. The project began in the summer of 2021 through private funding research, senior projects, and class projects. Initial work included the collecting and consolidating of the pertinent mechanisms for storing and processing data.

The first step was to collect the data electronically so that data can be enhanced and analyzed be software technologies. This required converting the paper forms into a collaborative data base that can be analyzed and processed by software either already developed or modified as required.[2]

Artificial Intelligence Methods Explored:

The team moved to the second step to evaluate the most appropriate technologies, methods, and tools

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[2] Disclaimer: this is a rough outline and not necessarily the final user interface (UI). This is largely built and is now moving to system level testing. Component and the UI will be modified as usability testing requires.

available. The project is looking at the practical application for artificial intelligence and not trying to present in this paper a very theoretical description of all these advanced technologies.

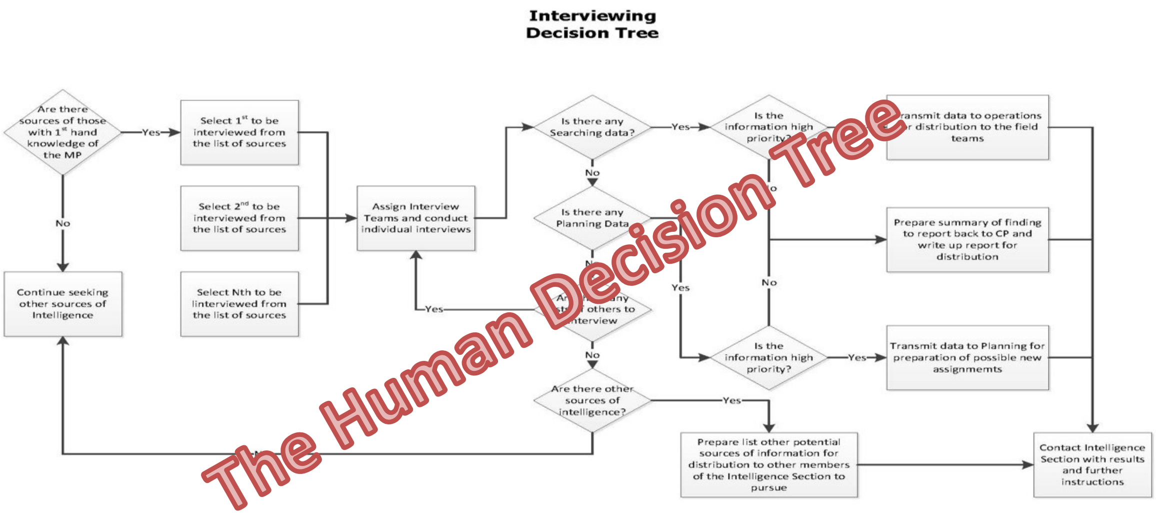
The Semantic Web: (Wikipedia, 2022)
With an ontology as the structural backbone of a knowledge repository, sematic web technologies are used for knowledge retrieval and reasoning over a wide range of digital documents. Ideally, documents should be described through metadata, but methods and tools are available to generate metadata from plain documents such as text files, databases, images, diagrams, and other formats. [Deductive reasoning and inference]

Some of the challenges with the semantic web (Wikipedia, 2022)

- Vastness – There are billions of pages of existing ontological knowledge to search through.
- Vagueness – The imprecise concepts like “young” and “tall”. (so called “fuzzy logic”)
- Uncertainty – There are too many variables – e.g.: medical symptom there are many different diagnoses. These can be partially resolved using Probabilistic Reasoning
- Inconsistency – The logical contradictions between combined ontologies
- Deceit – Data intentionally misleading requires the need to confirm and verify the knowledge [data] by human intervention.

Probabilistic Reasoning (Demartini, et.al., 2013)
This approach using probabilities can be used to explore relationships in data sets, predict the outcomes of actions and evaluate possible causes of events. The outcome could generate possible missing person scenarios. This is used in predicting lost person behavior (Koester, 2008)

Machine Learning: (Wikipedia, 2022)
Using the objectives to classify data based on models which have been developed from training data and to make predictions for future outcomes based on these models. Machine learning training can be supervised or unsupervised. Supervised consists of training data from examples from real incidents supplied by subject matter experts. This would also incorporate the use of decision trees:


Interviewing
Decision Tree
Are there sources of those with 1st hand knowledge of the MP
Yes
No
Select 1st to be interviewed from the list of sources
Select 2nd to be interviewed from the list of sources
Select Nth to be linterviewed from the list of sources
Continue seeking other sources of Intelligence
Assign Interview Teams and conduct individual interviews
Is there any Searching data?
Yes
No
Is there any Planning Data
Yes
No
Are there any others to interview
Yes
No
Are there other sources of intelligence?
Yes
No
Is the information high priority?
No
Transmit data to operations for distribution to the field teams
Prepare summary of finding to report back to CP and write up report for distribution
No
Is the information high priority?
Yes
Transmit data to Planning for preparation of possible new assignmemts
Prepare list other potential sources of information for distribution to other members of the Intelligence Section to pursue
Contact Intelligence Section with results and further instructions
The Human Decision Tree

Source (Young, 2022)

Unsupervised learning generates actions based on what it has already learned e.g., cluster analysis based on similarities from existing data sources such as the International Search and Rescue Incident Database (ISRID) used to develop Dr. Robert Koester's (2008) Lost Person Behavior book.

Deep Learning: (Wikipedia, 2022)

In this context, the use of Deep Learning in Natural Language Processing is especially relevant. Deep learning is a class of machine learning algorithms that use multiple layers to extract higher levels of features. E.g., lower levels of lines and edges to higher levels to extract digits, letters, or faces.

Hybrid Systems

While hybrid methods combining multiple artificial intelligence approaches have been explored for a long time, recent advances, combined with more easily available and lower cost computer capacity, have led to approaches that combine symbol-oriented methods (like the Semantic Web) with Machine and Deep Learning and Probabilistic Methods.

Evaluation of Technologies and Tools

The above approaches have yielded implementations of varying scopes, ranging from experimental research systems to large- scale commercial applications. The aspects to consider are capabilities, availability (e.g.: licensing, cost), reliability, scalability, and performance.

Computing Requirements:

The Initial requirements are cloud level of computing capacity to set up the models where incredibly large amounts of data capacity can be crunched. The cloud can handle this very economically, but will require evaluation of:

- What the connectivity is required whether intermittent, on demand, or 100 percent of the time. If constant connectivity to the cloud is required, then it may be necessary to consider satellite/cloud connections.
- Consider using virtual management from lessons learned during the COVID outbreak.
- Connectivity from field personnel to command post.

Once the model is developed, applying the model could potentially be done on a laptop given today's computing capacity.

System Architecture & Database Organization:

There are two parts to the system architecture and data base organization referred to as front and back-end development. To date the front-end uses JavaScript and Node.js to develop and manage the system and Redux to handle predictable state. The back end uses JSON to develop schemas and security rules for the digital forms as data is entered.

Experiments

The project team has and is continuing to identify interesting tools and conducting experiments to assess their suitability and performance in a missing person incident environment. This will include the use of available data sets in the search and rescue area, in particular data about past search missions. (e.g.: Lost Person Behavior ISRID database (Koester, 2008)). Based on the outcomes of the experiments, the project team will examine the practical aspects of a particular tool or technology to determine if it is a suitable candidate to be incorporated into the larger system This includes compatibility with other tools, licensing terms and conditions, financial aspects, and other factors.

Project Milestones Completed to Date:

By the end of the academic year 2021-2022, the project team successfully converted the BASARC and ICS forms into the Firebase database which required creating schema, security rules and integrating a search engine within the database. The front-end teams have established and are testing the connections between front end forms and submissions stored in the database that allows users to enter data on laptops, tablets and smart phones. An initial dashboard has also been created, evaluated, and modified as testing progresses. One of the challenges still to be resolved is to present everything in such a way that the end users do not have to learn database technology and to improve the navigation of the forms for searchers using the technology in the field. This foundational development work is largely completed and supports real-time collection of search data, improved distribution of the data and electronic storage of search information.

Future Research to be Present in Part 2 of this Paper:

This Part 1 paper has set the foundational data collection and management components for the further development of the use of artificial intelligence for search and rescue (which has now been abbreviated "AI4SaR") and missing person incidents. The next exciting part is how to analyze and apply some of the newest technologies to improve search outcomes with real-time analysis of the data as it is collected and stored electronically in the database. There will be extensive testing using past missing person search data as well as mock tabletop and, in the field, real time practical events.

Beyond the implementation and the research work around AI4SaR there is also the need for commercialization of the system which means looking for partners that are interested taking this from a professor/student lead effort to a commercial enterprise

Acronyms

AI	Artificial Intelligence
AI4SaR	Artificial Intelligence for Search and Rescue
BASARC	Bay Area Search and Rescue Council
Cal Poly	California Polytechnic State University
FEMA	The Federal Emergency Management Agency
ICS	Incident Command System
ISRID	International Search and Rescue Incident Database
MPI	Missing person incidents
MPQ	Missing person questionnaire
NIMS	National Incident Management System
SAR	Search and Rescue

Glossary

Firebase (Wikipedia, 2023)
Firebase is a set of backend cloud computing services and application development platforms provided by Google. It hosts databases, services, authentication, and integration for a variety of applications, including Android, iOS, JavaScript, Node.js, Java, Unity, PHP, and C++.

JavaScipt: (Wikipedia, 2023)
JavaScript is a software programing language and is one of the standards used by the World Wide Web.

JSON (JavaScript Object Notation) **(Wikipedia, 2023)**

JSON is an open standard file format encoding schema for data and data interchange ability with human-readable text.

Node.js (Wikipedia, 2023)
Node.js is a cross platform, open-source server environment and is used as the library in JavaScript to write commands.

React (Wikipedia, 2023)
React (also known as React.js or ReactJS) is a free and open-source front end JavaScript library for building user interfaces based on defined components.

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Appendix A

List of digitized forms for data collection:

Incident Command System:

ICS Form #:	Form Title:	Typically Prepared by:
ICS 201	**Incident Briefing**	Initial Incident Commander
ICS 202	**Incident Objectives**	Planning Section Chief
ICS 203	**Organization Assignment List**	Resources Unit Leader
ICS 204	**Assignment List**	Resources Unit Leader and Operations Section Chief
ICS 205	**Incident Radio Communications Plan**	Communications Unit Leader
ICS 205A	**Communications List**	Communications Unit Leader
ICS 206	**Medical Plan**	Medical Unit Leader (reviewed by Safety Officer)
ICS 207	**Incident Organization Chart** *(wall-mount size*	*optional 8½" x 14")* Resources Unit Leader
ICS 208	**Safety Message/Plan**	Safety Officer
ICS 209	**Incident Status Summary**	Situation Unit Leader
ICS 210	**Resource Status Change**	Communications Unit Leader
ICS 211	**Incident Check-In List** *(optional 8½" x 14" and 11" x 17")*	Resources Unit/Check-In Recorder
ICS 213	**General Message** *(3-part form)*	Any Message Originator
ICS 214	**Activity Log** *(optional 2-sided form)*	All Sections and Units
ICS 215	**Operational Planning Worksheet** *(optional 8½" x 14" and 11" x 17")*	Operations Section Chief
ICS 215A	**Incident Action Plan Safety Analysis**	Safety Officer
ICS 218	**Support Vehicle/Equipment Inventory** *(optional 8½" x 14" and 11" x 17")*	Ground Support Unit
ICS 219-1 to ICS 219-8	**ICS 219-10** ***(Cards)***	**Resource Status Card (T-Card)** *(may be printed on cardstock)* Resources Unit
ICS 220	**Air Operations Summary Worksheet**	Operations Section Chief or Air Branch Director
ICS 221	**Demobilization Check-Out**	Demobilization Unit Leader
ICS 225	**Incident Personnel Performance Rating**	Supervisor at the incident

Search and Rescue specific forms developed by the Bay Area Search and Rescue Council (BASARC)

SAR 100	**General Briefing**	
SAR 100A	**General Briefing Missing Person**	
SAR 104	**Team Assignment**	
SAR 110	**Team Debriefing**	
SAR 111	**Team Debriefing – Dog Team Supplement**	
SAR 112	**Team Debriefing – Area Search Supplement**	
SAR 113	**Team Debriefing – Equestrian Supplement**	
SAR 115	**Team Debriefing – Tracking Team Supplement**	
SAR 116	**Team Debriefing – Hasty Search Supplement**	
SAR 119	**Team Debriefing – Supplement**	
SAR131	**Individual Availability Assessment**	
SAR132	**Urban Interview Log**	
SAR133	**Radio Log**	
SAR134	**Clue Log**	
SAR132	**Clue Report**	
SAR139	**Event Missing/Found Person Report Form**	
	Missing Person Questionnaire (MPQ)	
	Backcountry Interview Log	