Determining Probabilistic Spatial Patterns of Lost Persons and their Detection Characteristics in Land Search & Rescue

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To

SPK & HPK

fellow students,

learners, and teachers

on the journey of life

Contents

Acknowledgments

Acronyms and Abbreviations

4wd	four-wheel drive
A	Area
AC	adult and child
ACIM	A Child is Missing
AD	Alzheimer's disease
ADRD	Alzheimer's disease and Related Disorders
AFB	Air Force Base
AFRCC	Air Force Rescue Coordination Center
A–GPS	Assisted–Global Positioning System
AHJ	Agency Having Jurisdiction
AKRCC	Alaska Rescue Coordination Center
AMDR	Average Maximum Detection Range
ANOVA	analysis of variance
AOR	area of responsibility
API	Application Program Interface
ASAP	as soon as possible
ASD	autism spectrum disorders
ASRC	Appalachian Search & Rescue Conference
ATV	all-terrain vehicle
BASE	Buildings Antennae Spans Earth
BOLO	Be On the Look Out
BYU	Brigham Young University
C	coverage
CAP	Civil Air Patrol
CASIE	Computer Aided Search Information Exchange
CASP	Computer Aided Search Planner
Cf	correction factor
cm	centimetre
CONUS	continental United States
CPA	closest point of approach
CSV	comma separated values

DAD	Disability Assessment for Dementia
DAT	Dementia of Alzheimer's Type
DD MM SS	Degrees Minutes Seconds Format
DD MM.MM	Degrees Decimal Minute Format
DD.DDD	Decimal Degree Format
DEM	Department of Emergency Management
DES	Department of Emergency Services
DF	direction finding
DHS	Department of Homeland Security
DOA	dead on arrival
DRG	Digital Raster Graphic
DSM	Diagnostic and Statistical Manual of Mental Disorders
DW	Distance Watershed
E/W	east/west
ED	emergency department
ELT	Emergency Locator Transmitter
EMA	Emergency Management Agency
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
EOC	Emergency Operations Center
EOTD	Enhanced Observed Time of Difference
EP	Estimated Position
ESW	effective sweep width
EVAC	Endangered & Vulnerable Adults and Children
F	female
FAA	Federal Aviation Administration
FBI	Federal Bureau of Investigation
FBO	Fixed Base Operator
FCC	Federal Communication Commission
FEMA	Federal Emergency Management Agency
FF	all female group
FOIA	Freedom of Information Act
FPM	feet per minute
FRS	Family Radio Service
ft	feet

FTL	Field Team Leader
GEOS	Global Emergency Operations Service
GIS	Geographic Information System
GMRS	General Mobile Radio Service
GPS	Global Positioning System
h	hour
HUC	hydrologic unit code
Hx	history
IADL	Instrumental activities of daily living
IAMSAR	International Aeronautical Maritime SAR Manual
ICAO	International Civil Aviation Organization
ICP	Incident Command Post
ICS	Incident Command System
IDEA	Integrated Detection Experiment Assistant
IFR	instrument flight rules
IGT4SAR	Integrated Geospatial Tools for Search and Rescue
IMC	instrument meteorological conditions
IMO	International Maritime Organization
IPP	initial planning point
IRG	Initial Response Guidelines
IRSG	Initial Response Search Guide
ISRID	International Search & Rescue Incident Database
kg	kilogram
km	kilometer/kilometre
kph	kilometers/kilometre per hour
KS	Kolmogorov-Smirnov
kts	knots
LCQ	Lost Caver Questionnaire
LIDAR	Light Detection and Ranging
LKP	last known point
LORAN	Long Range Navigation
LPB	Lost Person Behavior
LPQ	Lost Person Questionnaire

m	metre/meter
M	male
mb	millibars
MF	mixed sex group
MGRS	Military Grid Reference System
min	minutes
MM	all male group
MMSE	Mini-Mental Status Exam
MPQ	Missing Person Questionnaire
MRA	Mountain Rescue Association
n	count
N/S	north/south
NASAR	National Search & Rescue Association
NCIC	National Crime Information Center
NCMEC	National Center for Missing and Exploited Children
NCRC	National Cave Rescue Commission
NFPA	National Fire Protection Association
NHD	National Hydrological Data
NLCD	National Land Classification Data
nmi	nautical miles
NOAA	National Oceanic & Atmospheric Administration
NPS	National Park Service
NSARC	National Search and Rescue Committee
NSP	National Ski Patrol
NSS	National Speleological Society
NSS	National SAR Secretariat
NSS	National Search and Rescue Supplement
NTAM	New Two Area Method
NTAP	National Track Analysis Program
NTSB	National Transportation Safety Board
NVG	night vision goggles
OEBRD	Austrian Mountain Rescue Organization
OEG	Operations Evaluation Group
OFA	Operational Field Assessment
OPS	Operations Section Chief
OS	operating system

PANI	Pseudo Automatic Number Identification
PDD	pervasive developmental disorder
Pden	probability density
PDS	Progressive Deterioration Scale
PFD	personal flotation device
PI	principal investigator
PIW	person in the water
PKB	person, knees, boots
PL	private line
PLB	Personal Locator Beacon
PLS	point last seen
POA	probability of area
POC	probability of containment
POS	probability of success
PSAP	Public Safety Answering Point
PSAR	Preventative Search and Rescue
PSR	probable success rate
R	region
R&D	research and development
RADES	Radar Evaluation Squadron (84th)
Rd	range of detection
Rd	detection range
Re	extinguish range
RF	radio frequency
ROW	rest of the world
rPLS/LKP	revised place last seen/last known position
s	segment
S	track spacing
SAR	Search and Rescue
SARCAT	Search and Rescue Collection & Analysis Tool
SARINZ	Search and Rescue in New Zealand
SAROPS	Search and Rescue Optimal Planning System
SBIR	Small Business Innovation Research
SD	standard deviation
SEND	Satellite Emergency Notification Device
SIS	subject information sheet

SMS	Short Message Service
SRU	Search and Rescue Unit
SSI	Subjective Severity Index
T	time
T2NET	Travel Time Network Model
TAF	Task Assignment Form
TDOA	Time Difference of Arrival
TLL	track line length
TOA	Time of Arrival
TTCSM	Travel Time Cost Surface Model
UAV	unmanned aerial vehicle
UK	United Kingdom
US&R	Urban Search & Rescue
USAF	United States Air Force
USAR	Urban Search and Rescue
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USNG	United States National Grid
U-TDOA	Uplink Time Difference of Arrival
UTM	Universal Trans Mercator
V	velocity (or speed)
VASARCO	Virginia Search and Rescue Council
VDEM	Virginia Department of Emergency Management
VDES	Virginia Department of Emergency Services
VFR	visual flight rules
VMC	visual meteorological conditions

W	effective sweep width
WASO	Washington Support Office
WEMS	Wilderenss Emergency Medical Services
WEMT	Wilderness Emergency Medical Technician
WiSAR	Wilderness Search and Rescue
wk	week
WW II	World War II
Wx	weather
XML	Extensible Markup Language
Z	area effectively swept

Abstract

Search theory allows the optimization of scarce resources to find a missing person in the shortest possible time. This work focuses on the central paradigm in search theory from a land-based search and rescue perspective: A search planner must send a resource where the subject is located, which is unknown. Original research furthered search theory in probability of area (POA) by adding the dementia subject category, development of new spatial models, and creating the International Search and Rescue Incident Database (145,000 incidents). Research methodology required developing new data standards to integrate multiple databases. Twenty new subject categories were formulated from the research, as well as heuristic rules based upon search theory. In addition, several models were developed to help predict the location of missing aircraft. A program called Map-Score was created which quantizes the effectiveness of the models. This information has been widely adopted by search and rescue planners around the world.

The second component is the conditional probability that the searcher/sensor would detect the subject if the subject were in the search area; this is known as probability of detection. Sweep width experiments have been carried out in order to develop the methodology, create tools to simplify the process, determine actual sweep width values for visual search, and to examine various correction factors. The visual methodology was modified in order to carry out the two-way search problem of detecting subject shouts in response to whistle-blasts along with characterizing clues on a trail. Finally, with enough sweep width experiments completed it was possible to determine the correlation between the easily obtained range of detection and the experimentally derived sweep width, providing a quick field estimation tool. Optimal resource allocation can be obtained by maximizing the probability of success rate. This is determined by using previous research to determine POA, sweep width values and additional research that determined searcher velocity by GIS analysis. Ultimately, all search theory is integrated into a tactical decision aid, which for the first time will allow the search and rescue planner to easily use search theory.

Commentary

This work is primarily focused on both aspects of the central paradigm in search and rescue theory. In order to find the missing subject, a searcher must look in the right place and look in the right way to make an actual detection. This can be expressed by the following formula: the probability of success (POS) is equal to the product of the probability that the subject is in the defined search area (POA)[1] and the conditional probability that the searcher/sensor would detect the subject if the subject were in the search area (POD). This is shown in **Formula 1**, as first demonstrated by Charnes and Cooper (1958). Furthermore, the overall probability of success (POS) can be optimized by determining the probability of success rate (PSR). The theory then must be translated into clear recommendations and practices that field practitioners can successfully implement.

$$OPOS = \sum POS = \sum(POD*POA) \qquad (1)$$

The submitted body of work covers original work into both aspects of probability of area (POA) and probability of detection (POD). The POA works arose from an operational observation that lost people with dementia were behaving quite differently from the then existing behavioral profile of "elderly subjects" (Syrotuck, 1974). The earliest research by Koester (Koester & Stooksbury, 1992) created the dementia behavioral profile. A more formal study enlarged the study size and showed that the "lost" cognitively healthy population was in fact spatially different than those with dementia (Koester & Stooksbury, 1995). A funded prospective study introduced several new spatial models, such as track offset (perpendicular distance to the closest linear feature), find location (geographic feature similar to USA National Land Classification Data), and mobility (amount of time subject stays in motion tied to travel cost data). In addition, the previous statistical display of the distance from the initial planning point (IPP) and elevation was changed to make the data more relevant and useful to search planners (Koester, 1998). After introducing these spa-

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1   In maritime search and rescue the term Probability of Containment (POC) is often used (IAMSAR Manual: 2016) However, in land search and rescue the term Probability of Area (POA) is the preferred term (Washburn 2014). Although Koopman 1946, who is regarded as the father of modern search theory, used the term *f(r)d*A to denote the probability that the target be in the area, the term later become POC. They are functionally equivalent.

tial models in the early dementia papers, this work was further expanded by the creation of the International Search & Rescue Incident database (ISRID). With the collection of 50,692 SAR incidents it was possible to create dozens of new subject categories and spatial models which are published in the book *Lost Person Behavior (*Koester, 2008*)*. This body of work not only addressed missing subjects but also missing aircraft (Koester, 2009; Koester & Greatbatch, 2016). The ISRID database has led to extensive interactions with academic researchers (Doherty, Guo, Doke & Ferguson, 2013; Drexel, Zimmermann-Janschitz & Koester, 2018; Shalev Greene & Alys, 2016; Stone, Royset & Washburn, 2016; Washburn, 2014). The exchange of ideas has also occurred in 93 presentations at academic and trade symposiums along with more than forty-seven interactions with the media as of December 2018. More recently, ISRID has been expanded to almost 150,000 incidents (Koester, 2016a).

The body of work has fundamentally changed how search and rescue is conducted in many parts of the world. The underlying concepts have been also widely cited (currently 53 citations of *Lost Person Behavior*) and numerous collaborations with academic researchers have occurred. The concept of "reflex tasking" (data driven heuristic rules for tactical deployment based upon search theory) has been purported to reduce the time taken to locate missing subjects by 50%; resulting in hundreds if not thousands of lives saved[2]. This is similar to the increase in efficiency as a result of the US Navy introducing a tactical decision aid using search theory (Benkoski, 1978). Furthermore, the concepts and data from *Lost Person Behavior* are used by the US Inland SAR School, *US Land Search and Rescue Addendum to the National Search and Rescue Supplement* (NSARC, 2011), and presented in the leading SAR textbooks (Auerbach, 2017; Cooper, 2018; NSARC, 2011; Smith, LaValla, Hood, Lawson & Kerr, 2007; Stoffel & Stoffel, 2017).

However, simply putting teams in the subject's most likely location still does not guarantee finding the subject. The subject must be detected by the searchers. The sec-

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2 The study (D15PX00256) was funded by the US Department of Homeland Security Science & Technology Directorate as part of the US National Science Foundation I-Corps program. A hundred search managers from across the United States were asked how much of a reduction if any occurred after the use of *Lost Person Behavior* data and reflex tasking versus before. Many respondents noted that "campaign" searches are now rare. The average reduction in search time reported was 50%. Unpublished report.

ond body of research addresses the scientific method required to objectively determine a search team's probability of detection (POD). The determination of POD is well characterized for the maritime environment (IAMSAR, 2016). However, due to a divergence between maritime and land SAR, search theory was not being used to determine POD on land (Cooper, Frost & Robe, 2003).Thus, research on this second component of the central paradigm began.

The first paper describes the adoption of an original methodology for determining the effective sweep width in the terrestrial environment and the results of the first five experiments (Koester, Cooper, Frost, & Robe, 2004). Additional work describes experiments involving sound, light, and nighttime detections (Koester, Gordon, Wells, & Tucker, 2013). It was also realized that formal experiments cannot be easily carried out during actual search incidents. Thus, additional work was conducted to describe how simple field procedures can be translated to effective sweep width values (Koester et al., 2014). Along with this research were efforts to describe correction factors to better obtain more accurate sweep width values. Examples include visibility classes, size, day versus night, fatigue, flashlight light lumens, and searcher training. This is all part of a continuum of experiments to create easy but valid "rules of thumb" for searchers to use in the field to better estimate their POD. This has been an evolutionary process, with research building on previous work (Koester, 2016a). This research is also being incorporated into various search and rescue textbooks and major training courses (Cooper, 2018; NSARC 2011; Stoffel & Stoffel, 2017).

The third body of work stems from further refining the various models using Geographic Information Systems (GIS), which is part of a large US Department of Homeland Security Science & Technology Directorate grant. Results of this work include two new spatial models, collaboration on an objective method to score spatial models (Sava, Twardy, Koester & Sonwalker, 2016), an exploration of a Monte Carlo based particle motion model, and the formulation of new predictive models for searcher speed (Koester, 2014, 2016a). Finally, the fusion of spatial data, GIS, integration of all the POA models, POD, and search theory are coming together in new software (Koester, 2016a). It is hoped that this will revolutionize ground search and rescue by making advanced search theo-

ry accessible to a search planner with little to no training, even at the onset of a search incident. The body of work represents scientifically sound original research, and often the product of collaboration. This research is cited in academic literature (currently 206 citations in Google Scholar) and advances the literature in SAR research. It is used in government reports and training (NSARC, 2011), presented in textbooks (Cooper, 2018; Stoffel & Stoffel, 2017;), and perhaps most important of all, it is used every day around the world by field practitioners[3].

Probability of Area (POA)

It is well-accepted that if the missing subject's location is known with enough certainty, the process ceases to be a search and becomes a rescue. Since a search by its very nature involves uncertainty, probabilities are introduced (Koopman, 1946). The most central of all uncertainties is the location of the missing subject. Three different methods (particle motion, consensus, and stochastic) have been used to determine the initial distribution of POA, which has been handled differently in maritime and land search theory. The maritime approach involves the uncertainty of the initial fix or track of the missing vessel and then applying a circular normal distribution around it (IAMSAR, 2016). Tactical decision aids, such as the US Coast Guard's Search and Rescue Optimal Planning System (SAROPS), will then apply a particle motion model using a Monte Carlo simulation to determine the initial Probability of Area/Containment (Kratzhe, Stone, & Frost, 2010). In the land environment the traditional and most common way to determine initial POA is a manual method, called a Mattson consensus (Mattson, 1976). The scientific basis and value of a consensus method based upon informed opinion is well established (Surowiecki, 2004). Over time the basic process has been further refined with the traditional Mattson (1976), O'Conner (O'Conner, 2007), and Proportional methods (NSARC, 2011). In land SAR, the stochastic approach of integrating six different models (ring, dispersion, elevation, offset, mobility, and terrain) based upon previous cases was first described by Koester (2008). This approach was first integrated into a POA map using ArcGIS by ESRI as a demonstration project (ArcNews, 2012; Sarow, 2011). Ultimately it should be possible

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3   Lost Person Behavior Train-the-Trainer classes have been presented in North America, Europe, and Australia with additional classes taught in South America, Asia, Africa, Antarctica, and Oceania.

to integrate all three approaches into a SAR tactical decision aids.

In order to use a stochastic approach previous incidents must first be collected and typically organized to provide useful information (Burrough, 1989). The earliest known recorded collection of SAR statistics dates back to 1783. Father Lorenzo, a monk at the St. Gotthard Hospice, a monastery in Switzerland, reported an average of 3-4 deaths each year due to avalanches and freezing (Setnicka, 1980)[4]. In 1973, Dennis Kelley, an operations analyst, collected 380 case histories from his own search and rescue team in California. He reported on mobility, age, search outcome, mortality cause, injury cause, reason for becoming lost, and how long they were lost. It was William Syrotuck (1976), also an operations researcher, who made a significant impact on the land SAR community. Using 229 incidents from Washington and New York states, he devised subject categories, introduced the concept of point last seen (PLS), provided distances from the PLS using Euclidean distance (crow's flight), and noted the influence of terrain. He also introduced the use of basic statistics to land SAR (Syrotuck, 1976).

The National Association for Search and Rescue (NASAR) initiated a larger collection project in 1980. In 1985, Mitchell reported on the results of collecting 3,511 incidents from the United States. He was the first to show important regional differences; he introduced mobility time and collected survival factors as well (Mitchell, 1985). Ken Hill (1991) reported on 107 cases from Nova Scotia. He introduced new subject categories including "walkways" and youth (13-15), and reported the first statistics for despondents. Hill's had a background as a SAR practitioner and academic research in behavior. In 1999, Hill published an anthology titled *Lost Person Behaviour,* a collection of papers, by prominent SAR researchers including Kelley (1973), Syrotuck (1976), Koester & Stooksbury (1995), and Cornell & Heth (1996). Contributions by Koester will be addressed later in this section.

Heth and Cornell (1997) reported on 162 incidents from Alberta, Canada. They introduced the subject categories of car camper, cross-country skier, mountain biker, and scrambler. In addition, the paper introduced a new spatial model called degree of dispersion. The release of the first report on data from the Mountain Rescue Council (UK) was

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4   Correspondence by the author with the Monastery to obtain a copy of these early records resulted in a reply letter stating that Napoleon had burned the actual records.

in 2002 by Perkins, Roberts, and Feeney, presenting 708 cases collected from the United Kingdom and Eire. They were the first to report on gender differences, urban versus non-urban, and introduced the find location spatial model.

Gibb and Woolnough (2007) published "*Missing Persons: Understanding, Planning, Responding*" (often referred to as the Grampian data) which contained 3,000 incidents collected from only law enforcement agencies in the UK. The database focused on mostly urban environments and was the first to add the subject category of attention deficit hyperactivity disorder (ADHD). Several additional POA related studies are reviewed by Koester (2008). Since that review additional key contributions have included the iFIND database (Eales, 2016). Which contribute new subject categories of Asperger's syndrome, Genetic Condition, Post Traumatic Stress Disorder, Personality Disorder, Eating Disorder, Financial Problems, and Grief. It reports new statistics on gender, group breakdown, and distances traveled if a vehicle or transport was used. Missing Person research in the UK has also been assisted by the formation of the UK Missing Persons Unit within the National Crime Agency (UK Missing Persons Unit, 2018) and The Centre for the Study of Missing Persons, a multidisciplinary academic center established within the University of Portsmouth (University of Portsmouth, 2018). Additional studies include the watershed model derived from 213 incidents collected from Yosemite National Park (Doke, 2012); cost-distance models (Doherty, Guo, Doke, & Ferguson, 2014); missing person incidents associated with repeated IPP locations (Greene & Hayden, 2014); additional research into substance intoxication among males (Newis & Greatbatch, 2017); a new travel time network model (T2Net)(Drexel, Zimmermann-Janschitz, & Koester, 2018), and the weighing of models (Wysokinski & Marcjan, 2015). The additional contributions by Koester will be addressed in the review of key papers below.

In the early 1990s, search incidents for people with dementia were becoming more common and at the same time, posing a special challenge to search planners. There was no statistics or models for searching for lost persons with dementia. Syrotuck (1976) had an elderly subject category, but this included everyone over the age of 65; it lumped together elderly hunters or hikers with subjects who had dementia. Therefore, Koester decided to perform a study to determine if a new subject category of dementia was warranted.

David Stooksbury, a fellow Incident Commander and Ph.D. Candidate at the University of Virginia, was enlisted to help with the statistical analysis. A retrospective study of search incidents from 1986-1991 was collected from the Virginia Department of Emergency Services[5] (Koester & Stooksbury, 1992). Twenty-nine (12%) out of the 245 state incidents involved possible Alzheimer's subjects over the five-year period of retrospective incident review and included a description of distances traveled, find locations, subjects crossing containment (roads), and medical outcomes. The study made several recommendations on team deployment and search tactics. At the time, the study still reported the distances from the PLS in the same format as Syrotuck (1976). The study also showed several statistical differences between those with dementia and subjects over the age of 65 without dementia. The major limitations of the study included its retrospective nature, a relatively small number of incidents, lack of distinguishing between urban and non-urban searches, and a limited number of spatial models. However, it did have practical applications: it created a new subject category that search practitioners needed. Although the paper was published in the now discontinued and non-indexed *Journal of Response* it has been citied thirteen times in Google Scholar and has appeared in search and rescue textbooks.

A follow-up study was conducted in 1995 with 42 dementia incidents, also collected from Virginia (Koester & Stooksbury, 1995). While the retrospective methodology remained largely the same, the statistical analysis and descriptions were much more robust. The term commonly used at the time to describe suspected Alzheimer's cases was "dementia of Alzheimer's type" (DAT). Only later would the much more generic and appropriate term of dementia be used to describe the subject category. The paper formally compared the DAT subjects' behavior to the behavior of elderly lost subjects who possessed typical cognitive abilities. It was found that typical elderly individuals on average traveled a greater Euclidean distance (2.6 km) from the point last seen (PLS) than did DAT subjects (0.9 km). The mortality rate for DAT subjects was 19%. Mortality was caused by hypothermia, dehydration or drowning. No fatalities were found among subjects when they were located within 24 hours. There was a mortality rate of 46% for subjects requiring more than 24 hours to find. This 24-hour survivability window suggests that lost DAT subjects

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5   The department has been renamed to the Virginia Department of Emergency Management.

require an immediate and aggressive search response (Koester & Stooksbury, 1995). The survivability statistic became a widely cited statistic with 44 citations in Google Scholar. Furthermore, this work lead to numerous academic presentations and collaboration with the US Alzheimer's Association.

A limitation of both studies was the retrospective study design. To rectify this, Koester obtained funding from the Virginia Center on Aging to conduct a prospective study[6]. This allowed the design of survey tools, the ability to interview search subjects and caregivers, and improved data collection. With better data, Koester (1998) developed several new spatial models. The term DAT evolved to 'Alzheimer's Disease and Related Disorders' (ADRD). Data was again collected from the Virginia Department of Emergency Services database of search incidents, missing person reports, after action reports, mission summaries, and from structured interviews with missing subjects and/or caregivers, resulting in a total of eighty-seven (15%) ADRD incidents of 565 total recorded state incidents. Distances were reported using quartiles and the use of the maximum zone representing the 95.4% was introduced to SAR statistics. The study reported on survivability (a 21% mortality rate) and the increase in mortality to 32% if the subject was not found within 24 hours of becoming lost. This was a decrease from the previously reported value of 50% (Koester & Stooksbury, 1995). It demonstrates the value of collecting additional statistics when working with smaller sample sizes. Other findings included, seasonality with more incidents occurring during the summer than the winter, and males significantly (χ^2=44.8, p<0.001) accounted for 67% of searches although females are more likely to have ADRD.

In the few cases where a direction of travel could be determined, it was shown to be highly predictive, with the find location showing a significant clustering around that direction (Rayleigh test; p<0.001). A new spatial model was introduced called track offset, in which subjects were found a median of 30 meters from a linear feature. The term "investigative find" was introduced to replace the more pejorative term "bastard case" (Koester, 1998). Both the prospective and retrospective nature of this study allowed the addition of new models which further helped to guide searchers on where to look. The major limitation of this study was the limited geographical area (Virginia) it covered. Search teams

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6   Virginia Center on Aging 97-2 with funding to the Virginia Department of Emergency Services

from other states such as Colorado and New Mexico often stated the reported statistics did not always match what they were seeing in their searches. This paper has received 35 citations in Google Scholar and lead to two other publications (Koester,1999; Steinberg et al., 2012) and collaboration with the Virginia Department of Criminal Justice to establish dementia training for law enforcement. This training has reached thousands of police officers across the United States.

Based upon the research in creating the dementia profile and the work of creating profiles for despondents, intellectual disability[7], and mental illness,[8] Koester was contacted by Jim Donovan (CEO of Hummingbird) to help create a large lost person database. Donovan had just been awarded a Small Business Innovation Research (SBIR) contract from the United States Department of Agriculture to develop search and rescue software. The initial Phase I was a 6 month contract within which time period the data needed to be collected. This was a major constraint. However, this effort then resulted in a two-year Phase II award with Koester being listed as the co-principal investigator[9]. From this work the International Search & Rescue Incident Database (ISRID) was created. A major constraint of ISRID was the requirement that it had to be initially completed within six-months. Later this data would be used to help provide initial POAs within FIND software (Koester, 2016a). Data was accepted from governments and Non-governmental Organizations throughout the world in whatever format supplied, provided it met the inclusion/exclusion criteria. Therefore, extensive efforts went into data entry, formatting, and data cleaning.

From the ISRID database it was possible to write the book *Lost Person Behavior*, which describes ISRID and its outputs organized into subject categories (Koester, 2008). One major challenge of combining data from all over the world (thirteen countries and forty different data sources) was how to make the data relevant and predictive for individual in-

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7   In keeping with terminology used by the World Health Organization at the time, the original term used was mental retardation. This work was presented at the fourth Syrotuck International Symposium in Banff 1998. It was included in a search and rescue textbook (Stoffel, 2001)

8   The original term used was psychotic, which is only a subset of mental illness. This work was also presented at the fourth Syrotuck International Symposium in Banff 1998. It was included in a search and rescue textbook (Stoffel, 2001)

9   USDA 2004-33610-14779 – Developing Software for Search and Rescue Planning and Operation

cidents. One important innovation was organizing statistics around major ecoregions and treating urban data as its own unique ecoregion. Data was further divided into mountainous and non-mountainous categories. In the end, it was possible to provide information on forty-one subject categories with six different spatial models. New subject categories included aircraft, ATV, autism, caver, gatherer, horseback, BASE jumper, extreme sports, motorcycle, runner, skier-alpine, snowboarder, snowmobiler, snowshoer, substance intoxication, urban entrapment, vehicle, abandoned vehicle, water, and worker. In addition to the six spatial models, statistics were provided on scenarios and survivability. The book also contained a review of the literature with over 250 references. It has sold over 25,000 copies. It is used as a textbook in several college courses, and is cited in other primary SAR textbooks (Cooper (2018); NSARC (2011); O'Conner (2007); Stoffel & Stoffel (2013); Stoffel & Stoffel (2017); Stone et al. (2016); and Washburn (2014)), wilderness medical textbooks (Auerbach (2017); Beebe & Myers (2011); and Hawkins, (2018)), cited in other academic books (Friedman (2017); Glaus (2014); Greene & Alys 2016); Hammond (2013); Kaufman, Kaufman & Moiseichik (2013)), in popular books (Huth (2013); and Jenner (2015)), and has received 53 citations in Google Scholar.

After finishing *Lost Person Behavior,* NASA contracted with Koester to provide additional missing aircraft data and provide a more detailed database. The goal was to use NASA World Wind software as a Tactical Decision Aid (NASA, 2009). This additional collection of data was reported in a government report (Koester, 2009). This report was copied into the Civil Air Patrol Research Papers (Civil Air Patrol, 2009) and a data adapted for the USAF Inland SAR School. Koester and Greatbatch (2016) furthered this work by looking at the spatial characteristics of missing aircraft in actual distress. The purpose of this study was to characterize this distance and then identify environmental and flight characteristics that might be used to predict the spatial relationship between the last radar fix and the final location and, therefore, aid search and rescue planners. Detailed records were obtained from the United States Air Force Rescue Coordination Center for missing aircraft in distress from 2002 to 2008. The data was combined with information from the National Transportation Safety Board (NTSB) Accident Database. The spatial relationship between the last radar plot and crash site was then determined using GIS analysis. A total

of 260 missing aircraft incidents involving 509 people were examined, of which 216 (83%) contained radar information. Among the missing aircraft the mortality rate was 89%; most accidents occurred in mountainous terrain (57%); and 50% of the aircraft were found within 0.8 nautical miles from the last radar plot. Flight characteristics, descent rate, icing conditions, and instrument flight rule versus visual flight rule could be used to predict spatial characteristics. In most circumstances, the last radar position is an excellent predictor of the crash site. However, 5% of aircraft are found further than 45.4 nautical miles. The flight and environmental conditions were identified and placed into an algorithm to aid search planners in determining how factors should be prioritized and which statistical tables to use for planning search operations (Koester & Greatbatch, 2016).

As data and the spatial models from ISRID continued to be used by search planners an important question arose of just how well does each of the models predict finding the subject? From subjective experience it was felt that some of the spatial models might be more predictive than others. Therefore, a way to weigh the models could improve the overall effectiveness of any tool that combined all of the spatial models. With funding from the United States Department of Homeland Security Science and Technology Directorate (DHS S&T), as part of a new SBIR with Koester as the principal investigator, it was possible to support a tool to score POA models. Previous work by Rossmo (1999) had created a scoring metric for models. The Rossmo metric considered a model, grid squares, and where the subject was actually located. Then it scored the ratio of the total number of predicted points with scores equal or higher than the actual find location to the total number of points within the entire search area.

However, it was felt that an equivocal model that assigned equal probability to the entire search area (which would score a perfect score of 1.0) would not be operationally useful and should not be rewarded. Therefore, a modification to the Rossmo metric was made as described in the paper describing MapScore (Sava et al., 2016). The MapScore project provides a way to evaluate probability maps using actual historical searches (provided from the ISRID database). In this work probability maps with the Euclidean distance tables in Koester (2008), and using Doke's (2012) watershed model were generated. Watershed boundaries follow high terrain and may better reflect actual barriers to travel. A

third model using the combination of the Euclidean (ring) and watershed features was also scored. On a metric where random maps score 0 and perfect maps score 1, the Euclidean distance model scored 0.78 (95%CI: 0.74–0.82). The watershed model by itself was clearly inferior at 0.61, but the combined model was slightly better at 0.81 (95%CI: 0.77–0.84) (Sava et al., 2016). It is the long term plan to use MapScore to evaluate each of the spatial models, determine a weighted value to each of the spatial models, and then create an algorithm to combine them in such a way to get the optimal operational result. A similar approach has also been described using ISRID data by Wysokinski & Marcjan, (2015). This work has been cited twelve times in Google Scholar. Although, determining where to look is critical, it is still only half of the equation to actually finding the missing subject.

Probability of Detection (POD)

A comprehensive review of search theory and POD was conducted by Benkoski, Monticino, and Weisinger (1991). Since then additional contributions to POD in search theory have been numerous. Washburn (2016) has recently addressed detection models, different sensors, lateral range curve, stationary targets, moving targets, multiple targets, and false alarms. In Stone et al. (2016), the focus was on moving targets. Iida (1993) discusses an inverse Nth power detection law based upon the lateral range curve. Stone, Keller, Kratze, and Strumpfer (2014) have shown how prior POD from different sensors changed the a priori in the search for AF447. Frost (1999a, 1999b, 1999c) has also published a series of articles on general search theory that was directed at a land SAR audience.

The development of formal search theory, particularly POD, in the land SAR discipline has not paralleled the aeronautical or maritime discipline. Search theory has been adapted in several other fields, such as archaeology (Stewart et al., 2015), fishing (Mangel & Clark, 1983), mining (De Geoffroy & Wignall, 1985) or weed control (Baxter & Possingham, 2011). Cooper, Frost, and Robe (2003) provide a comprehensive review of the use/non-use of search theory in land SAR. One of the earliest land SAR texts by Bridge (1960) makes no mention of search theory. This is not too surprising since Koopman's work was not declassified until 1956 (Koopman, 1946). In fact, the first mention of search

theory was by Kelley (1973) who cites Koopman (1956). Wartes (1974) conducted the first land-based POD experiments during the day and at night. His methodology precludes a direct comparison of results to sweep width experiments, since he did not produce a lateral range curve, counted detection opportunities differently, and mixed different types of search objects. However, for a "spacing" of 30.5 meters between searchers a POD of 51% was obtained during the day and 19% at night for an "unconscious" human subject. Wartes (1974) reported that much of his POD results were based upon the spacing of the searchers. While not in his original report, his results were summarized as a formula that gave a POD based upon searcher spacing for all conditions in the land SAR textbooks of the time (LaValla, Stoffel & Jones, 1981). Bownds, Lovelock, McHugh, and Wright (1981) conducted a POD experiment in the Arizona desert using a helicopter search crew as the sensor looking for non-high-visibility people on the ground. A similar experiment was conducted in mountainous terrain in Arizona by Bownds, Harlan, Lovelock, and McHugh (1991), with the helicopter flying either a descending contour search or a route search pattern.

Perkins (1989) described a method of determining POD called "critical separation," whereby a spacing between searchers at twice the maximum detection range while moving away from the intended search object results in a POD of 50%. This was the first technique in land SAR to account for the search object and the environment. However, it did not account for search effort. In the paper, Perkins (1989) noted that he conducted empirical testing, spacing the searchers at one critical separation but allowing the searchers to wander within their lanes to investigate any features. They reported an actual POD of 80%, which can be accounted for by the extra effort in the trackline, resulting in a greater coverage. Colwell (1992) conducted POD experiments in the Pacific Northwest and reported POD results based upon different spacings. He reported different curves depending upon the search object or sensor (sound sweep, high visibility sweep, standard sweep, and low visibility sweep). Even in 1996 the USAF National Search and Rescue School *Inland SAR Coursebook* (1996) did not address lateral range curves, sweep width, coverage, or detection models. Thus, it is somewhat understandable that the land SAR discipline was not aware of formal search theory and how it handled POD.

Robe and Frost (2002) were the first to conduct an effective sweep width experiment on land, demonstrating that even in the highly variable land environment, the distance between the searcher and the search object is the most important factor. They also introduced the use of the cross-over technique to obtain the actual sweep width value from the often highly variable lateral range curve. The methodology was improved and a series of five additional experiments were carried out in different types of terrain and times of the year (Koester et al., 2004). These experiments will be detailed later. Chiacchia and Houlahan (2010) collected sweep width values for different search objects and noted some correction factors involving youth in SAR. These experiments also involved improvements to the methodology and the first use of Integrated Design Experiment & Analysis (IDEA) which automates the experimental design, data collection, and data analysis for land-based sweep width experiments (Koester, Guerra, Frost, & Cooper, 2006). While in most experiments the search sensor was visual detection during the daytime, experiments have been conducted to determine the sweep width value for mounted searchers on horses (Koester et al., 2004), for air-scent dogs representing olfactory search (Chiacchia, Houlahan & Hostetter, 2015), and for auditory search (Koester et al., 2013). Koester et al. (2014) reviewed land-based visual effective sweep width experiments. This paper will also be discussed later. These efforts have made land SAR POD research consistent with formal search theory.

After the study of compatibility of land SAR procedures with search theory (Cooper et al., 2003), the USCG funded a pilot study to determine whether it is possible to determine a sweep width value in the land environment at low cost. The pilot study was conducted, but it almost failed to produce results because the subjects (trash bags filled with balloons) had not been placed far enough away from the track (Robe & Frost, 2002). This led to further USCG funding for five additional experiments. Koester was hired as the principal investigator and conducted experiments in Virginia (two), New Mexico, California, and Washington State (Koester et al., 2004). The report describes several enhancements, changes, and innovations to the methodology. In order to eventually assist others in designing experiments, a software tool was developed (Integrated Design Experiment & Analysis) to assist in the design, collection, and analysis of data (IDEA, 2006). Standard

search objects (stuffed coveralls) were constructed based upon research of clothing worn by subjects on actual ground missions and standard human dimensions. Modifications were made on how to scout and layout the experiment track. Changes were made in how to determine the Average Maximum Detection Range (AMDR). Several additional methods to characterize the vegetation and terrain were added. Laying out the actual search objects was greatly simplified by the development of the IDEA software tool (IDEA, 2006). The software enabled the data to be scored, documented, analyzed and plotted, which further simplified the process.

During the experiments described by Koester et al. (2004), experienced searchers participated in the five experiments; with an averaged 8.7 years in SAR and 47 searches. The search speed was remarkably consistent in all five experiments, with searchers moving at 1.75 km/hr on average. The environmental measurements, including AMDR, varied widely at each experiment, as expected due to different ecoregions. Sweep width values ranged from 142 meters for a high-visibility adult in the Virginia forest (Hot Continental Eco-region) during the winter to 17 meters for a low-visibility adult in the dense Washington forest (Marine Eco-region) during the spring. A possible relationship was also found between AMDR and sweep width.

Several potential correction factors were measured to determine whether they influenced the sweep width. Unexpectedly, the results indicated that search experience did not improve the number of detections. The age of the searcher showed that the probability of detection (POD) increased up to the age of 40 and then started to decline. Searcher speed when kept between 1-3 km/h did not affect sweep width. Searcher's height, color-blindness, self-reported morale, and self-reported fatigue had dramatic effects on sweep-width (Koester, et al., 2004). Observations on height were actually confounded with age, as later studies would find (Chiacchia et al., 2004). Gender was found to have no effect. Perhaps the most important result was that the sweep width results could easily be obtained in the ground environment and that the scoring and analysis became highly automated (Koester et al., 2004).

The final broad goal of the research was to develop a methodology that other SAR teams could easily follow to determine sweep width values for terrain and foliage in their

own area of responsibility. To further refine the methodology and automate experiment planning with IDEA, additional USCG funding was secured to enhance and test the methodology (Koester et al., 2006). This resulted in additional sweep width studies carried out by others (Chiacchia & Houlahan, 2010; Chiacchia et al., 2015) and several unpublished experiments[10]. While Koester et al. (2004) has been cited twenty times in Google Scholar, the major goal of comprehensive sweep width tables akin to the IAMSAR manual (2016) has not been realized. The methodology, while easy to carry out, is not easily understandable to a non-researcher. In addition, the organization and human resources required to carry out an experiment are extensive. Therefore, the need for some robust simplified tool became apparent.

Sweep width experiments are not limited to visual searching. The Search and Rescue Institute in New Zealand (SARINZ) funded a study to determine the sweep width value of its sound sweep technique. The experiment was unique because searching with sound is a two-way (cooperative) search problem rather than a one-way (uncooperative) search problem, which is more common (Lie & Wang, 2017). When the searcher sends out a whistle-blast, the subject must detect the signal, choose to respond, shout-back; finally, the searcher must be able to detect the return shout. This required several changes to the visual methodology previously described (Koester et al., 2004, 2006).

Two experimental trials were carried out at Nelson Lakes in New Zealand (Koester, et al., 2016). The first experiment was conducted during the day with six subjects and fourteen two-person teams using a sound line tactic. The detection index for a subject hearing a whistle blast was 401 meters. The detection index for a search team detecting the returned shout was 332 meters. Searchers were able to detect 99% of high-visibility clues (orange gloves) and 52% of low-visibility clues (gray gloves) on the track. The night experiment was conducted at the same location, but with different search subjects placed in different locations. Search teams used a sound-light line tactic in two-person teams. The detection index for a subject hearing a whistle was 395 meters and seeing a light 277 meters. The detection index for a subject detecting either signal was 460 meters. The

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10   We are aware of unpublished experiments that took place in Massachusetts, Arizona, Michigan, and Iceland.

detection index for a search team hearing the reply shout was 306 meters. This is the first report in the land search literature of both elements (searcher and subject) of a two-way detection problem (Koester et al., 2016). This experiment showed some of the complexity of sound detection and critical factors involved. These results will be integrated into search and rescue software (Koester, 2016a). However, once again it was demonstrated that a full-blown sweep width experiment is resource intensive.

Therefore, the need existed to find a short-cut or proxy to sweep width values. Koester et al. (2004) had already suggested a possible relationship between Average Maximum Detection Range (AMDR) and sweep width (W). With additional sweep width experiments being performed, it was possible to review the data and look for a mathematical relationship (Koester, et al., 2014). A robust empirical correlation between detection range (Rd) and W was found that may be used as a quick field estimate for W. The previously reported average maximum detection range (AMDR), Rd, and W values from 10 detection experiments were used. The study also provided a review of all known sweep width experiments including several which had not been previously published. The study measured the correlation between Rd and W, and tested whether the apparent relationship between W and Rd was statistically significant. It was found on average $W \approx 1.645 \times Rd$ with a strong correlation ($R^2 = .827$). The paper then set out the correlation for three different visibility classes. The correction factor was $W \approx 1.8 \times Rd$ for high-visibility subjects, the medium-visibility class had $W \approx 1.6 \times Rd$, and the low-visibility class had a correction factor of 1.1 for Rd to W. A high correlation between the AMDR and Rd ($R^2 = .9974$) was also reported (Koester et al., 2014). The use of the range of detection (Rd) method is much simpler than an AMDR procedure and doesn't require laser range finders for measurements. The Rd procedure now appears in search and rescue textbooks for both field resources and management (Stoffel & Stoffel, 2013, 2017). In addition, the paper has been cited in four other sources in Google Scholar.

Search Optimization

While POA is about putting the team in the right place and POD is concerned with the team making a detection, search theory involves one final important concept. Since limited search resources are almost always the normal, an optimal allocation of scarce resources is needed. **Formula two** for the probability of success rate (PSR) combines all of these elements, where W is the effective sweep width, V is the velocity of the search resource, and Pden is the probability density or POA divided by the size of the search area. The PSR is the instantaneous rate of change in POS for adding one more increment of effort (search resource) to the search (NSARC, 2011). Thus an optimal search plan attains the maximum PSR possible from the available resources (Frost, 1999c).

$$PSR = W * V * Pden \quad (2)$$

Koester was awarded an SBIR contract from the United States Department of Homeland Security Science & Technology Directorate in order to create a tactical deci-sion aid that would integrate search theory, mapping, and incident management into one comprehensive package[11]. During the Phase I six-month work effort, ISRID was expanded from 50,692 incidents to 145,155 incidents, the database was moved from Excel to R, a data collection tool was built (SARCAT), 700 GPS tracks were obtained from searchers to estimate searcher velocity, MapScore was funded to score spatial models, and a new spatial model for revised Place Last Seen or revised Last Known Position was developed (Koester, 2014). A follow on contract was then awarded for Phase II[12]. Based upon the updated ISRID summary data a new field book (*Endangered & Vulnerable Adults and Children*) was written which included the updated statistics, tactical briefings, and the new subject category of medical (Koester, 2016b). In addition, SARCAT software was imple-mented and started collecting SAR incident data (SARCAT, 2016).

Finally the Lost Person Behavior App became available for Android, iOS, and Blackberry operating systems (Lost Person Behavior, 2015). The Phase II funding also

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11   Phase I – DHS S&T HSHQDC-13-C-00107 ($100,000)

12   Phase II – DHS S&T D14PC00153 ($1,050,000), DHS S&T NSF I-Corp – D15PX00256 ($50,000)

allowed applied research on:

- creation of a parametric model for distance from the Initial Planning Point (IPP),

- additional data collection and cleaning for ISRID, documentation for ISRID, formal statistical testing of ecoregions,

- creation of a point model, testing of a particle motion model,

- collection of range of detection (Rd) from all National Land Classification Data types and from all forest types as classified by the *National Atlas of the US*,

- additional searcher velocity based upon slope and search type,

- further improvements to MapScore and use of MapScore to test combining models,

- examine survivability modeling, and

- the development of the tactical decision aid known as FIND (Koester, 2016b).

The FIND software is documented in the *Search and Rescue Initial Response Tools DHS S&T Phase II Report* (Koester, 2016a). The FIND software consists of TotalTopo which is 14-zoom-level topographic map, built from more than twenty sources. Other base maps are integrated as well. The search theory component allows the integration of eight different stochastic spatial models based upon ISRID data. The computer model can be integrated with the traditional Mattson if it has been conducted. The search area is then broken into smaller areas using an auto-segment rule. For each potential search sector, the probability density (Pden) and Probability of Success Rate (PSR) are displayed. The calculation of PSR requires the Pden value, recognizing slope and land features to determine velocity, and then recognizes either the National Land Classification Data or forest type to determine the sweep width (W) value. Tasks may be sorted based upon the PSR or Pden ranking. Once a task is completed, an extensive set of algorithms were developed to determine the POD. Several different methods are documented in a POD white paper that was written. The software also takes advantage of various incident management tools to track and update all of the relevant data (Koester, 2016a). While the software has not

been commercially released at this time, it has been tested during operational exercises and passed its DHS Operational Field Assessment[13].

An important component of the FIND software is the ability to visualize the quartile data from each of the spatial models and then integrate them so they may be visualized all at once. Examples of each of the spatial models appear in the search and rescue chapter (Conover, Circh, Koester, 2018) in the textbook *Wilderness EMS* (Hawkins, 2018). The chapter also provides the reader with an overview of search theory. It covers POA, reflex tasking, POD, ISRID, PSR, and tactical decision aids. As a textbook, it integrates and presents much of the previously described research in a practical way to demonstrate how it is used operationally on a search and rescue incident.

Contributions & Theoretical Framework

This body of academic work started with two simple questions: *where is the subject? - and why did the team miss them?* From the first study (Koester & Stooksbury, 1992), conducted as a practitioner addressing a gap in knowledge to new spatial models that require advanced GIS capabilities (Koester, 2016; Drexel, Janschitz, & Koester, 2018), significant contributions to the field have been made. The POA research started with a small data set from just Virginia looking only at dementia (Koester & Stooksbury, 1992). The next two papers (Koester & Stooksbury, 1995; Koester, 1998) build upon this work by increasing the size of the database, performing statistical analysis, and introducing new and novel spatial models to better characterize dementia wanderers. This approach culminated in the publication of Lost Person Behavior (Koester, 2008), which presented six spatial models, built upon the ISRID database, introduced the novel approach of presenting data based upon ecoregions, and created many new subject categories. The building of the dementia wandering profile built upon field observations from multiple search incidents. A personal database was transformed to an actual objective database. Intuitive observations where then transformed to objective spatial models. Research methodology largely consisted of defining terms and creating new data standards where none existed.

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13   Warner, B., Patel, B. (2016) FIND Lost Person Locator, Operational Field Assessment Report, DHS Science & Technology Directorate, National Urban Security Technology Laboratory (Report Marked FOUO and not for public release)

This body of work is now widely used in applied practice around the world as evidenced by academic citations, widespread use of the book, and citation in primary SAR textbooks.

In Koester & Greatbatch (2016), a single subject category (missing aircraft) was examined in-depth with a new theoretical construct to better define which conditions should be prioritized to maximize probability density. In Sara et al., (2016), another spatial model (watershed) was introduced, but more importantly the value of combining models is directly quantified and found to be beneficial. Combining models is the entire theoretical foundation of the approach used in the FIND software (Koester, 2016a). The ability to measure each model along with combined models with the MapScore metric was a theoretical breakthrough along with the success in the actual methodology that made it possible. The various models are both illustrated in Conover, Circh, and Koester (2018) and illustrate the research being adopted into more general textbooks. In Drexel, Janschitz, & Koester (2018) the mobility model is refined by using a more streamlined model building approach and then assessed using a different theoretical approach of using Pden (much like in Koester & Greatbatch, 2016) instead of the MapScore approach (Sava et al., 2016). While not previously discussed, the use of Pden to evaluate models may represent a silver standard while the MapScore approach is more robust. Each approach had advantages and disadvantages which warrant further exploration.

The theoretical approach in search theory for determining the POD of a resource's effort was already well established (Frost, 1999b). However, for the land environment a new experimental methodology was required and to identify any potential correction factors. Koester et al., (2004) and Koester et al., (2006) refined the methodology suitable for the land environment. This body of work also started the process of identifying and quantifying correction factors. Unfortunately, a sweep width experiment is only valid for the conditions it is held or for determining potential correction factors. Therefore, Koester et al (2014) reviewed all land based sweep width experiments conducted and found a theoretical relationship between the sweep width value and the Rd value. The use of Rd values has allowed the determination of prospective W values by conducting Rd experiments in NLCD classes and forest type groups (Koester, 2016a). This represented a significant step in actually using search theory in the field. Prior to this work, it was impossible to

have prior ESW values. This represents both a theoretical break through along with one in research methodology. In addition, to visual search, other sensors are used in SAR. Koester et al., (2013) looked at auditory sensors for the two-way search problem. New on-going research is looking at multiple sensors (EO and IR) used on UAVs. All of this work is critical to a unified search theory approached found in the FIND software (Koester, 2016a). In this way all theoretical POD work along with critical correction factors is made more practical and placed into the hands of the SAR practitioners without the need to conduct any math themselves.

The FIND software is the culmination of research efforts contribution to search theory packaged into an intuitive tactical design aid for SAR practitioners. It would not be possible without a comprehensive database that is made relevant by ecoregions and terrain, new spatial models that can be integrated, relevant subject categories, integration with scenario analysis through subject matter export input, the ability to use Rd to predict the prospective W values, development of correction factors, display of PSR in a relevant fashion, Bayesian updates based upon actual searching, and a new more simple approach to search optimization. All of these tools are also packaged with the incident management tools and geospatial mapping so that the field searcher, mission manager, and search planner all get what they need.

Limitations

Unlike aeronautical and maritime SAR, land SAR has no international organizing body (IAMSAR, 2016). In many countries, land SAR is either delegated to the lowest governmental entity or to non-governmental organizations (NSARC, 2011). Therefore, international standards, databases, and common practices often do not exist. The greatest limitation to research into probability of area has been collecting quality incident data. When incident data does exist, it is often difficult to obtain, usually low quality, lacks critical fields, lacks any standards, and typically requires extensive data cleaning. Few SAR databases are mandatory (Greatbatch, Koester & Kleinsmith, 2018). In many cases it exists only in paper forms. Incident data is the key to most future research such as agent based modeling, development of new statistical models, validation of models, influence of environ-

mental factors, role of psychological factors, survival predictions, creation of new subject categories, and many other research needs. For example, the development of new subject categories by definition means it isn't an existing tick box or option on most forms. Only well-constructed data collection instruments allow data collection on unusual cases. SARCAT is an example of a data collection tool based upon the written data standards that were used to construct ISRID (SBIR paper). However, this represents a voluntary standard. However, due to a lack of mandatory reporting requirements at any level, this freely available tool hasn't been widely adopted at this time.

The major limitation of POD research is the tremendous human resources required to construct and carryout experiments. It was for this reason the use of Rd to determine the ESW was examined and found to be valid (Koester et al., 2014). However, this still leaves 1330 different environment to determine the Rd value (Koester et al., 2014). It is hoped that various correction factors may reduce this number greatly. However, conducting ESW experiments, which are still required to determine a valid correction factor, are often fraught with environmental uncertainty. In one experiment, set up with 50 searchers, it snowed during the critical window to carry-out the experiment. The snow selectively stuck only to the green polypropylene fabric targets and not the vegetation. This effectively turned the low-visibility targets into high contrast ones and invalidated the experiment. While, getting other searchers to conduct experiments was the stated goal of the USCG sponsored research (Koester et al., 2004), it has provided difficult due to the time and resources required. Therefore, the need for an alternative method to determine ESW short of a full blown experiment was required. In addition, visual searching isn't the only sensory modality used in the land environment. The land-based visual methodology has also been successfully modified for auditory and olfactory search resources (Chiacchia, Houlahan & Hostetter, 2015; Koester et al., 2013), however many other resource types remain untested. The repeatability of the experimental results has not been tested at this time, nor has a correction factor for variability between searchers been discovered. Trained searchers can vary as much as detecting 5 – 90% of the same visibility class on the same experimental course (Koester et al., 2004). This variability at some point needs to be accounted for in search theory. In the end, determining what makes a "good" or "bad" visual searcher

could be a huge contribution to the field. It is hope "bad" visual searchers could then be turned into "good" searchers.

Ongoing Collaborations

Sharing ISRID data and collaborations are currently taking place with Monash University (dementia and freedom), Rayerson University (dementia and drones), Linkoping University (improving data collection), and New Mexico State University (probability of detection with virtual reality). In addition, recent grant proposals have been successful in collaboration with Virginia Tech (NSF for machine learning with drones in a search and rescue environment) and George Mason University (Virginia Center for Aging for dementia and building particle motion models with machine learning). Probability of Detection is not limited to visual search; instead many different types of sensors can be used for search. Many of these sensors can be placed airborne on sUAVs.

Future Work

The tactical decision aid, FIND, supported by the US Department of Homeland Security is the current focus of research and development efforts. The FIND software integrates mapping, incident management, and search theory. It also automates many of the previous research findings into tools available to search planners. Future work on the mapping software, called TotalTopo which currently maps the entire United States, includes mapping other countries, adding more public safety facilities, updating trails, integrating user made changes and data, adding heli-spots, and updating USGS contour lines to custom contour lines based upon newer more accurate DEM data. The integration of search theory is a major innovation and builds upon previous POA and POD research and findings.

Future work on POA will include improving ISRID, data collection, POA models, further integration of the environment, and additional subject categories. New sources of incident data for ISRID are always being sought along with greater standardization and usefulness of the collected data through the free release of ISRID data standards and SARCAT (Koester, 2016a). This new data will further help with the rest of the research

goals. Three methods can be used to determine initial POA; a consensus of subject matter experts, an objective combining of statistical models, and an agent based particle motion model. FIND currently integrates the consensus and statistical models. Additional testing using MapScore (Sava et al., 2016) will help to determine if the different models should be weighed, the user should be given the ability to weigh models, or if they should always be given equal weight. Research into the third method, of using agent based models, has been started as part of the collaboration with the team at Virginia Tech as part of NSF funded research. Agent based modeling is much more sensitive to the period of time the subject has been missing. Currently, the statistical approach only takes into consideration the ecoregion domain and terrain. With additional data it should be possible to include the polar domain, and examine some key ecoregion divisions. In the polar domain, results may need to be divided into snow on or off the ground. All of the data may benefit from a closer examination of environmental conditions since Syrotuck (1976) reported differences in detectability. The newer models (Koester, 2016a) of the revised Place last Seen, point model, and watershed model require additional data analysis and refinement for each subject category. Integrating scenario analysis into the formal process is required. Preliminary work (Koester, 2016a) has already determined the statistical model results based upon different scenarios outlined in *Lost Person Behavior* (Koester, 2008). Finally, research into new subject categories will be undertaken for scenario based categories, brain trauma, BASE jumpers (including wingsuits), vision quest, cell phone forensics, and beacons. The goal of all of these various approaches remains the same, to better determine the possible locations of the missing person.

In search theory it is equally important to continue to improve determining the POD once a search resource has actually been deployed. Prospective sweep width values have been determined for major land classifications and forest types (Koester, 2016a). This initial work can easily be improved upon. Additional correction factors can be determined for northern or southern exposure, slope, and altitude. It may also be possible to estimate the sweep width by combining two-three observable factors and preclude the need to conduct an Rd test. Several additional correction factors to the initial sweep width value need to be tested. Some of these factors include; individual variability, searcher ve-

locity, and environmental factors (precipitation, wind, etc.). In order to determine the POD for responsive subjects the ability to hear a returned shout from a searcher's whistle blast requires a sweep width value. While Koester et al., (2013) determined an initial sweep width value, several correction factors are need to improve final results. Correction factors are needed for temperature, relative humidity, background noise, vegetation, wind, searcher and subject hearing losses, gender, and types of whistles being used. While sweep width values and some correction factors have been determined for three common search sensors (human visual search on foot, human visual search on horseback, and air-scent dogs) many other types of search resources and sensors need to be determined. Future testing is needed for ATV, bicycle, vehicle, helicopter, and fixed wing platforms with human visual search. In addition, preliminary testing has already begun for UAV based sensors including Electro-optical (EO) and infrared (IR). Current research funded by the Virginia Center for Innovative Technology is ongoing to determine sweep widths and correction factors[14]. UAV based sensor platforms will require various correction factors for sensor type (lines of resolution), optical lens field of view, velocity, Above Ground Level (AGL) altitude, camera tilt, canopy cover, visibility class, method used to view flight, and characteristics of the image analyst.

The underlying algorithms that drive FIND can always be improved. A particle motion model that takes into account subject categories remains elusive at this point, but with more and better data, time and effort, these problems can be solved. However, I have learned that practitioners often simply accept new findings without critical assessment (especially if it fits with prior beliefs); therefore critical and rigorous standards must be applied to all research results released to the SAR community. Continuous improvement even if incremental is critical when lives are at stake and minutes matter.

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14   Virginia Center for Innovative Technology SBIR16-023-US & SBIR17-041-US

References

ESRI. (2012). Modeling the movement of lost people. Retrieved from http://www.esri.com/news/arcnews/fall12articles/modeling-the-movement-of-lost-people.html

Auerbach, P. S. (Ed.) (2017). *Wilderness Medicine*. Philadelphia, PA: Elsevier.

Baxter, P. W. J. & Possingham, H. P. (2011). Optimizing search strategies for invasive pests: Learn before you leap. *Journal of Applied Ecology*, (48)1, 86-95.

Beebe, R., & Myers, J. (2011). *Trauma care & EMS operations.* Independence, KY. Delmar Cengage Learning.

Benkoski, S. (1978). Optimal use of the operational ASW search information system. *Commander Patrol Wings Atlantic Fleet Lessons Learned*. 261-279

Benkoski, S., Monticino, M., & Weisinger, J. (1991). A survey of the search theory literature. *Naval Research Logistics*, 38:469-494

Bownds, J., Harlan, A., Lovelock, D., & McHugh, C. (1991). *Mountain searches: Effectiveness of helicopters*. Fairfax, VA: National Association for Search and Rescue.

Bownds, J., Lovelock, D., McHugh, C., & Wright, A. (1981). *Desert searches: The effectiveness of helicopters.* Retrieved from www.math.arizona.edu/~dsl/casie/helicop.htm

Bridge, L. D. (1960). *Mountain search and rescue in New Zealand*. Wellington NZ: Federated Mountain Clubs of New Zealand.

Burrough, P. A. (1989). Matching spatial databases and quantitative models in land resource assessment. *Soil Use and Management, 5*(1), 3-8.

Charnes, A., & Cooper, W. W. (1958). The theory of search: Optimum distribution of search effort. *Management Science, (5)*, 44-50.

Chiacchia, K.B., Houlahan, H.E., & Hostetter, R.S. (2015). Deriving effective sweep width for air-scent dog teams. *Wilderness & Environmental Medicine, 26*(2), 142-9.

Chiacchia, K.B., & Houlahan, H.E. (2010). Effectors of visual search efficacy on the Allegheny Plateau. *Wilderness & Environmental Medicine, 21*,188-201.

Civil Air Patrol. (2009). *Missing aircraft research report*. Retrieved from https://static1. squarespace.com/static/52f294c6e4b0bede38b4d35c/t/5352adc0e4b053dc26fa1 4d3/1397927360694/Missing+Aircraft+Search+Research.pdf

Colwell, M. (1992). *New concepts for grid searching*. Search and Rescue Technical Publications Series, Vol 1(1). Olympia, Washington: International Search and Rescue Trade Association (INSARTA).

Conover, K., Circh, R., & Koester, R. (2018). Technical rescue interface: Search & rescue and non-snow/glacier mountaineering rescue. In S. C. Hawkins (Ed.), *Wilderness EMS (pp. 529-559)*. Alphen aan den Rijn, The Netherlands: Wolters-Kluwer.

Cooper, D. C. (2018). *Fundamentals of search and rescue* (2nd Edition). Boston, MA: Jones & Bartlett Publishers.

Cooper, D. C., Frost, J. R., & Robe, R. Q. (2003). Compatibility of land SAR procedures with search theory (Publication No. ADA511658). Alexandria, VA: Defense Technical Information Center. Retrieved from www.dtic.mil/get-tr-doc/ pdf?AD=ADA511658

Cornell, E. H., & Heth, C. D. (1996). Distance traveled during urban and suburban walks led by 3 to 13-year-olds. *Response! The Journal of the National Association for Search and Rescue*, *15*(1), 6-9.

De Geoffroy, J. G., & Wignall, T. K. (1985). Optimizing ore detection. In *Designing Optimal Strategies for Mineral Exploration* (pp. 75-94). New York, NY: Plenum Press.

Di Friedberg, M. S. (2017). *Geographies of Disorientation*. London, UK: Routledge.

Doherty, P. J., Guo, Q., Doke, J., & Ferguson, D. (2014). An analysis of probability of area techniques for missing persons in Yosemite National Park. *Applied Geography*, *47*, 99-110.

Doke, J. (2012). Analysis of search incidents and lost person behavior in Yosemite National Park. (Unpublished master's thesis). University of Kansas, Lawrence, KS.

Drexel, S., Zimmermann-Janschitz, S., & Koester, R. (2018). Network analysis for search areas in WiSAR operation. *International Journal of Emergency Services*. doi:10.1108/IJES-02-2017-0005

Eales, N. (2016). *iFIND*. National Crime Agency, UK Missing Persons Bureau.

Frost, J. R. (1999a). Principles of search theory, part I: Detection. *Response*,*17*(2), 1-7.

Frost, J. R. (1999b). Principles of search theory, part II: Effort, coverage, and POD. *Response*, *17*(2), 1-7.

Frost, J. R. (1999c). Principles of search theory, part IV: optimal effort allocation. *Response*,*17(2)*:11–23.

Gibb, G., & Woolnough, P. (2007). *Missing persons: Understanding, planning, responding*. Aberdeen, UK: Grampian Police.

Glaus, R. A. (2014). *The psychology of search and rescue*. Tigard, OR: Inkwater Press.

Greatbatch, I., Koester, R.J., & Kleinsmith, A.L. (2018). Rescue responses during a full moon and Friday 13th. International Journal of Emergency Services. doi:10.1108/IJES-12-2017-0066

Greene, K.S, & Alys, L. (Eds.) (2016). *Missing persons: A handbook of research*. London, UK: Routledge.

Greene, K. S., & Hayden, C. (2014). *Repeat reports to the police of missing people: Locations and characteristics*. Portsmouth, UK: University of Portsmouth, Centre for the Study of Missing Persons.

Hammond, S. C. (2013). Lessons of the lost: Finding hope and resilience in work, life, and the wilderness. Bloomington, IN: iUniverse.

Hawkins, S. C. (Ed.) (2018). *Wilderness EMS*. Philadelphia. PA: Wolters Kluwer.

Heth, D., & Cornell, E. (1997). Characteristics of travel by persons lost in Albertan wilderness areas. *Journal of Environmental Psychology 18*, 223-235.

Hill, K. (1991). Predicting the behavior of lost persons. *Response 91 – National Association for Search and Rescue Conference Proceedings*. Chantilly, VA: National Association for Search and Rescue.

Hill, K. (1999). *Lost Person Behaviour*. Ottawa: National Search and Rescue Secretariat.

Huth, J. E. (2013). *The lost art of finding our way*. Boston, MA: Harvard University Press.

IDEA (Integrated Detection Experiment Assistant)(for Windows). Version 1.0, Washington D.C.: United States Coast Guard Operations (G-OPR).

Iida, K. (1993). Inverse nth power detection law for Washburn's lateral range curve. *Journal Operations Research Society, 36*, 90-101.

International Civil Aviation & International Maritime Organization. (2016). *International Aeronautical and Maritime Search and Rescue Manual Vol. I—III (*2016 ed.). London, UK: International Maritime Organization.

Jenner, L. (2015). *Lost and gone away*. Auckland, NZ: Auckland University Press.

Kauffman, R. B., Kauffman, R., & Moiseichik, M. L. (2013). *Integrated risk management for leisure services*. Birmingham, AL: Human Kinetics.

Kelley, D. (1973). *Mountain search for the lost victim*. Montrose, CA: Privately published.

Koester, R. J. & Stooksbury, D. E. (1992). Lost Alzheimer's subjects: profiles and statistics. *Response, 11*(4), 20-26.

Koester, R. J. & Stooksbury, D. E. (1995). Behavioral profile of possible Alzheimer's disease subjects in search and rescue incidents in Virginia. *Wilderness and Environmental Medicine*, *6,* 34-43.

Koester, R. J. (1998). The lost Alzheimer's and related disorders subject: New research and perspectives. *Response 98 NASAR Proceedings*,165-181. Chantilly, VA: National Association of Search and Rescue.

Koester, R. (1999). *Lost Alzheimer's disease search management: A law enforcement guide to managing the initial response and investigation of the missing Alzheimer's disease subject*. Charlottesville, VA: dbS Productions.

Koester, R. J., Cooper, D. C., Frost, J. R., & Robe, R. Q. (2004). *Sweep width estimation for ground search and rescue.* Washington D.C.: U.S. Department of Homeland Security, United States Coast Guard Operations (G-OPR). DTIC. Retrieved from http://www.dtic.mil/get-tr-doc/pdf?AD=ADA511593

Koester, R. J., Guerra, N., Frost, J. R., & Cooper, D. C. (2006). *A simple guide to conducting ground search and rescue detection experiments Vol I & II*. Washington D.C: U.S. Department of Homeland Security, United States Coast Guard Office of Search and Rescue (G-RPR). Retrieved from http://www.dco.uscg.mil/Our-Organization/Assistant-Commandant-for-Response-Policy-CG-5R/Office-of-Incident-Management-Preparedness-CG-5RI/US-Coast-Guard-Office-of-Search-and-Rescue-CG-SAR/CG-SAR-2/Land-SAR/

Koester, R. J. (2008). *Lost person behavior: A search and rescue guide on where to look—for Land, Air, and Water*. Charlottesville, VA: dbS Productions.

Koester, R. J. (2009). *Data collection and analysis for NASA World Wind Search and Rescue Visualization Program.* National Aeronautics and Space Administration Search and Rescue Mission Office. Greenbelt, MD: Goddard Space Flight Center.

Koester, R. J., Gordon, R., Wells, T., & Tucker, R. (2013). Auditory and light based two-way effective sweep width for responsive search subjects in New Zealand mountainous terrain. *Journal of Search & Rescue, 1*(1),1-18. Retrieved from http://journalofsar.com/wp-content/uploads/2017/01/Auditory.pdf

Koester, R. J. (2014). *Final report SBIR Phase I: Lost person locator for first responders*. Washington D.C.: U.S. Department of Homeland Security, Science & Technology Directorate.

Koester, R. J., Chiacchia, K. B., Twardy, C. R., Cooper, D. C., Frost, J. R., & Robe, R. Q. (2014). Use of the visual range of detection to estimate effective sweep width for land search and rescue based on 10 detection experiments in North America. *Wilderness & Environmental Medicine*, 25(2),132-142

Koester, R. J., & Greatbatch, I. (2016). Missing aircraft crash site and spatial relationships to the last radar fix. *Aerospace Medicine and Human Performance 87*, (2), 114-121.

Koester, R. J. (2016a). *Final report SBIR Phase II: Search and rescue initial response tools.* Washington, DC: US Department of Homeland Security Science & Technology Directorate.

Koester, R. J. (2016b). *Endangered & vulnerable adults and children*. Charlottesville, VA: dbS Productions.

Koopman, A. (1946). *Search and screening* (Operations Evaluation Group Report 56). Alexandria, VA: Center for Naval Analysis,

Koopman, B. O. (1956). The theory of search, Part II: target detection. *Operations Research*, *4*, 503-531.

Kratzke, T., Stone, L., & Frost. J. (2010). Search and rescue optimal planning system. *Information Fusion (FUSION), 2010 13th Conference (*DTIC Publication No (ADA564779)*.* Symposium conducted at the meeting of IEEE, Edinburgh, UK.

LaValla, P., Stoffel, R. C., & Jones, A. S. G. (1981). *Search is an emergency*. Olympia, WA: Emergency Response Institute.

Liu, Q., & Wang, Q. (2017). A comparative study on uncooperative search models in survivor search and rescue. *Natural Hazards 89*, 843. doi.org/10.1007/s11069-017-2996-y

Lost Person Behavior (for Android, iOS, and Blackberry). (2015). Version 1.0.5, Charlottesville, VA: dbS Productions

Mangel, M., & Clark, C. W. (1983). *Uncertainty, search, and information in fisheries. Journal du Conseil,* 41(1), 93-103.

Mattson, R.J. (1976). Establishing search areas. *Search and Rescue Magazine*, *Spring 1976,* 7-8.

Mitchell, B. (1985). A summary of the National Association for Search and Rescue data collection and analysis program for 1980-1985. *Response 85, National Association for Search and Rescue Conference Proceedings*. Chantilly, VA: National Association for Search and Rescue.

NASA World Wind Search and Rescue Software. (2009). Available from https://worldwind.arc.nasa.gov/java/apps/SARApp/help/v6/SARHelp.html

National Search and Rescue Committee (2011). *Land search and rescue addendum to the National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual Version 1.0*. Washington D.C.: National Search and Rescue Committee. Retrieved from https://www.dco.uscg.mil/Portals/9/CG-5R/nsarc/Land_SAR_Addendum/Published_Land%20SAR%20Addendum%20(1118111)%20-%20Bookmark.pdf

Newis, G., & Greatbatch, I. (2017). *Men missing on a night out: Exploring the geography of fatal disappearances to inform search strategies*. Portsmouth, UK: University of Portsmouth Centre for the Study of Missing Persons.

O'Conner, D (Ed). (2007). *Managing the lost person incident*. Centerville, VA: NASAR.

Perkins, D. (1989). Critical separation: Its role in search management in theory and practice. In P. LaValla (Ed.), *Probability of detection (POD) research and other concepts for search management* (pp. 1-39). Olympia, Washington: Emergency Response Institute (ERI).

Perkins, D., Roberts, P. & Feeney, G., (2002). *Missing person behaviour: A U.K. study (full report).* Northumberland, UK: Centre for Search Research. Retrieved from http://www.searchresearch.org.uk

Robe, R.Q., & Frost, J. R. (2002). A method for determining effective sweep widths for land searches: Procedures for Conducting Detection Experiments. Alexandria, VA: Potomac Management Group.

Rossmo, D. K. (1999). *Geographic profiling*. Boca Raton: CRC Press.

SARCAT (Search and Rescue Collection & Analysis Tool) (Version 1.0) [Linux, Apache]. Charlottesville, VA: dbS Productions. Available from https://github.com/Azimuth1/SARCAT

Sarow, E. (2011) Determining probability of area for search and rescue using spatial analysis in ArcGIS 10. Unpublished report.

Sava, E., Twardy C., Koester, R., & Sonwalker, M. (2016). Evaluating lost person behavior models. *Transactions in GIS, 20*(1), 38-53

Setnicka, T. (1980). *Wilderness search and rescue*. Boston, MA: Appalachian Mountain Club.

Smith, R., LaValla, P., Hood, R., Lawson, N., & Kerr, G. (2007). *Basic search and rescue skills: A practioner's guide to search and rescue*. Olympia, WA: ERI International.

Steinberg, C., Saunders, G., Boltz, M., Hall, E., Hutchison, E., Koester, R., Lindeman, D., Powers, R., Rowe, M., Skone, J., & Songer, E. (2012). *Lost and found: A review of available methods and technologies to aid law enforcement in locating missing adults with dementia*. New York, NY: Alzheimer's Foundation of America.

Stewart, S. T., Banning, E. B., Edward, S., Hitchings, P. M., & Bikoulis, P. (2015). Predicting survey coverage through calibration: Sweep widths and survey in Cyprus and Jordan. *CAA 2015,* 613-622.

Stoffel, R. (2001). *The handbook for managing land search operations*. Cashmere, WA: ERI Publications & Training.

Stoffel, R., & Stoffel, B. (2013). *SAR skills for the emergency responder: Basic skills & knowledge*. Cashmere, WA: ERI Publications & Training.

Stoffel, B. C. & Stoffel, R. C. (Eds.) (2016). *Managing the inland search function*. Monitor, WA and Centerville, VA: Jointly published by ERI Publications & Training & The National Association for Search and Rescue.

Stone, L., Keller, C., Kratzke, T., & Strumpfer, J. (2014). Search for the wreckage of Air France flight AF 447. *Statistical Science, 29*(1), 69-80.

Stone, L. D., Royset, J. O., & Washburn, A. R. (2016). *Optimal search for moving targets*. Cham, Switzerland: Springer International Publishing.

Surowiecki, J. (2004). *The wisdom of crowds: Why the many are smarter than the few and how collective wisdom shapes business, economies, societies and nations.* New York, NY: Little Brown.

Syrotuck, W. (1976). *Analysis of lost person behavior: An aid to search planning.* Mechanicsburg, PA: Barkleigh Productions.

"University of Portsmouth" Centre for the Study of Missing Persons. 22 Apr. 2018, Retrieved from www.port.ac.uk/centre-for-the-study-of-missing-persons/.

"UK Missing Persons Unit" *UK Missing Persons Unit*, National Crime Agency. 22 Apr. 2018, Retrieved from www.missingpersons.police.uk/.

USAF. (1996). *Inland SAR Course*, Yorktown, VA: USAF National Search and Rescue School.

Wartes, J. (1974). *An experimental analysis of grid sweep searching*. Sunnyvale, CA: Western Region Explorer Search and Rescue (ESAR).

Washburn, A. (2014). *Search and detection* (5th ed). CreateSpace Independent Publishing Platform.

Wysokinski, M., Marcjan, R. (2015). Decision support system for search & rescue operations. *Computer Science*, *16*(3), 281-293.

Work Statement

Whilst registered as a candidate for Award of Doctor of Philosophy by Publication, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

Robert J. Koester

FORM UPR16

Research Ethics Review Checklist

Please include this completed form as an appendix to your thesis (see the Research Degrees Operational Handbook for more information

Postgraduate Research Student (PGRS) Information		Student ID:	80668

PGRS Name:	Robert J. Koester		
Department:	SEES	**First Supervisor:**	Dr. Richard Teeuw
Start Date: (or progression date for Prof Doc students)	October 2. 2017		

Study Mode and Route:	Part-time	☐	MPhil	☐	MD	☐
	Full-time	☒	PhD	☒	Professional Doctorate	☐

Title of Thesis:	Determining Probabilistic Spatial Patterns of Lost Persons and their Detection Characteristics in Land Search and Rescue
Thesis Word Count: (excluding ancillary data)	11,051 words, If including attached publications then 1500 pages.

If you are unsure about any of the following, please contact the local representative on your Faculty Ethics Committee for advice. Please note that it is your responsibility to follow the University's Ethics Policy and any relevant University, academic or professional guidelines in the conduct of your study

Although the Ethics Committee may have given your study a favourable opinion, the final responsibility for the ethical conduct of this work lies with the researcher(s).

UKRIO Finished Research Checklist:
(If you would like to know more about the checklist, please see your Faculty or Departmental Ethics Committee rep or see the online version of the full checklist at: http://www.ukrio.org/what-we-do/code-of-practice-for-research/)

a)	Have all of your research and findings been reported accurately, honestly and within a reasonable time frame?	YES NO	☒ ☐
b)	Have all contributions to knowledge been acknowledged?	YES NO	☒ ☐
c)	Have you complied with all agreements relating to intellectual property, publication and authorship?	YES NO	☒ ☐
d)	Has your research data been retained in a secure and accessible form and will it remain so for the required duration?	YES NO	☒ ☐
e)	Does your research comply with all legal, ethical, and contractual requirements?	YES NO	☒ ☐

Candidate Statement:

I have considered the ethical dimensions of the above named research project, and have successfully obtained the necessary ethical approval(s)

Ethical review number(s) from Faculty Ethics Committee (or from NRES/SCREC):	

If you have *not* submitted your work for ethical review, and/or you have answered 'No' to one or more of questions a) to e), please explain below why this is so:

PhD by publication: all relevant work and publications were completed prior to UoP registration. I have only public databases, collected no personnally identifiable info, and followed US regulations for government cont

Signed (PGRS):	*[signature]*	Date: 27th of July, 2018

UPR16 – April 2018

Statement of the extent of the Candidate's contribution to any of the submitted work which involves joint authorship or other type of collaboration

Probability of Area

Koester, R.J. & Stooksbury, D. E. (1992). Lost Alzheimer's subjects-profiles and statistics. *Response, 11*(4), 20-26. (Journal)
- Lead author. 90% Research, 90% Writing

Koester R.J. & Stooksbury D. E. (1995). Behavioral profile of possible Alzheimer's disease subjects in search and rescue Incidents in Virginia. *Wilderness and Environmental Medicine* 6, 34-43. (Journal)
- Lead author. 95% Research, 90% Writing

Koester R. J. (1998). The lost Alzheimer's and Related Disorders subject: new research and perspectives. *Response 98 NASAR Proceedings,*165-181*.* Chantilly, VA: National Association of Search and Rescue. (Conference Proceedings)
- Sole author. 100% Research, 100% Writing

Koester R. J. (2008). *Lost person behavior: A search and rescue guide on where to look - for land, air, and water.* Charlottesville, VA: dbS Productions. (Book)
- Sole author. 95% of research, 99% of writing. Chapter 5 was based upon information from Ken Hill with content additions by Koester and a complete rewrite of the words to keep a consistent writing tone. Data entry accomplished using a team of five to enter paper forms into an electronic database. Reviewers commented on specific sections and in some cases suggested specific verbiage.

Koester, R.J. & Greatbatch, I. (2016). Missing aircraft crash site and spatial relationships to the last radar fix. *Aerospace Medicine and Human Performance, 87,*(2), 114-121.(Journal)

- Lead author. 95% Research, 95% Writing

Sava E., Twardy, C., Koester, R. & Sonwalker, M. (2016). Evaluating lost person behavior models. *Transactions in GIS, 20*(1), 38-53. (Journal)

- Third author. Role in obtaining, cleaning, and providing all of the data that is used in MapScore. Funded the development of MapScore and provided feedback on its development. Provided the overall direction and funding for all of the work performed. Created the modification to the Rossmo algorithm used by MapScore to make it more relevant to search and rescue models. Reviewed, commented, and approved paper, methodologies, and data results, prior to submission.

Conover, K., Circh, R., & Koester, R. (2018). Technical rescue interface: Search & rescue and non-snow/glacier mountaineering rescue. In S. C. Hawkins (Ed.), *Wilderness EMS (pp. 529-559)*. Alphen aan den Rijn, The Netherlands: Wolters-Kluwer. (Chapter in a book)

- Third author. Role consisted of writing some pages and paragraphs, reviewing the chapter and making comments and suggestions, updating several of the references, and providing illustrations of models generated from the FIND software.

Drexel, S., Zimmermann-Janschitz, S., & Koester, R. (2018). Network analysis for search areas in WiSAR operation. *International Journal of Emergency Services*. doi:10.1108/IJES-02-2017-0005 (Journal)

- Third author. 10% Research, 10% writing. Provided original data from updated ISRID database which required appropriate filters. Wrote updated methodology describing data also commented and provided writing for review of literature, methodology, and abstract. Reviewed, commented, and approved paper.

Probability of Detection

Koester, R. J., Cooper, D. C., Frost, J. R., & Robe, R. Q. (2004). *Sweep Width Estimation for Ground Search and Rescue.* Washington D.C.: U.S. Department of Homeland Security, United States Coast Guard Operations (G-OPR). DTIC. Retrieved from http://www.dtic.mil/get-tr-doc/pdf?AD=ADA511593(Government Sponsored Report)
- Lead author. 75% Research, 80% Writing

Koester, R.J., Gordon, R., Wells, T. & Tucker, R. (2013). Auditory and light based two-way effective sweep width for responsive search subjects in New Zealand mountainous terrain. *Journal of Search & Rescue*. *1*(1)1-18. Retrieved from http://journalofsar.com/wp-content/uploads/2017/01/Auditory.pdf (Journal)
- Lead author. 90% Research, 97% Writing

Koester, R.J., Chiacchia, K.B., Twardy, C.R., Cooper, D.C., Frost, J.R. & Robe, R.Q. (2014). Use of the visual range of detection to estimate effective sweep width for land search and rescue based on 10 detection experiments in North America. *Wilderness & Environmental Medicine, 25*(2):132-142. (Journal)
- Lead author. 90% Research, 75% Writing

Search Optimization

Koester, R.J. (2014). *Final Report SBIR Phase I: Lost person locator for first responders.* Washington, DC: US Department of Homeland Security Science & Technology Directorate. (Government Sponsored Report)
- Sole author. 90% Research, 100% Writing

Koester, R.J. (2016). *Final Report SBIR Phase II: Search and rescue initial response tools*. Washington, DC: US Department of Homeland Security Science & Technology Directorate. (Government Sponsored Report)
- Sole author. 90% Research, 100% Writing

Listing of Submitted Publications
Probability of Area

Koester, R.J. & Stooksbury, D.E. (1992). Lost Alzheimer's subjects-profiles and statistics. *Response 11*(4), 20-26. (Journal)

Koester, R.J. & Stooksbury, D.E. (1995). Behavioral profile of possible Alzheimer's disease subjects in search and rescue Incidents in Virginia. *Wilderness and Environmental Medicine* 6, 34-43. (Journal)

Koester, R. J. (1998). The Lost Alzheimer's and Related Disorders Subject: New Research and Perspectives. *Response 98 NASAR Proceedings,* 165-181. Chantilly, VA: National Association of Search and Rescue. (Conference Proceedings)

Koester, R.J. (2008). *Lost person behavior: A search and rescue guide on where to look - for land, air, and water.* Charlottesville, VA: dbS Productions. (Book)

Koester, R.J. & Greatbatch, I. (2016). Missing aircraft crash site and spatial relationships to the last radar fix. *Aerospace Medicine and Human Performance.* 87 (2), 114-121 (Journal)

Sava, E., Twardy, C., Koester, R. & Sonwalker, M. (2016). Evaluating lost person behavior models. *Transactions in GIS*, 20(1), 38-53 (Journal)

Conover, K., Circh, R., & Koester, R. (2018). Technical rescue interface: Search & rescue and non-snow/glacier mountaineering rescue. In S. C. Hawkins (Ed.), *Wilderness EMS (pp. 529-559)*. Alphen aan den Rijn, The Netherlands: Wolters-Kluwer. (Chapter in book)

Drexel, S., Zimmermann-Janschitz, S., & Koester, R. (2018). Network analysis for search areas in WiSAR operation. International Journal of Emergency Services. doi:10.1108/ IJES-02-2017-0005.

Probability of Detection

Koester, R. J., Cooper, D. C., Frost, J. R., & Robe, R. Q. (2004). *Sweep Width Estimation for Ground Search and Rescue.* Washington D.C.: U.S. Department of Homeland Security, United States Coast Guard Operations (G-OPR). DTIC. Retrieved from http://www.dtic.mil/get-tr-doc/pdf?AD=ADA511593(Government Sponsored Report)

Koester, R.J., Gordon, R., Wells, T. & Tucker, R. (2013). Auditory and light based two-way effective sweep width for responsive search subjects in New Zealand mountainous terrain. *Journal of Search & Rescue*. *1*(1)1-18. Retrieved from http://journalofsar.com/ wp-content/uploads/2017/01/Auditory.pdf (Journal)

Koester, R.J., Chiacchia, K.B., Twardy, C.R., Cooper, D.C., Frost, J.R. & Robe, R.Q. (2014). Use of the visual range of detection to estimate effective sweep width for land search and rescue based on 10 detection experiments in North America. *Wilderness & Environmental Medicine, 25*(2):132-142. (Journal)

Search Optimization

Koester, R.J. (2014). *Final Report SBIR Phase I: Lost person locator for first responders.* Washington, DC: US Department of Homeland Security Science & Technology Directorate. (Government Sponsored Report)

Koester, R.J. (2016). *Final Report SBIR Phase II: Search and rescue initial response tools*. Washington, DC: US Department of Homeland Security Science & Technology Directorate. (Government Sponsored Report)
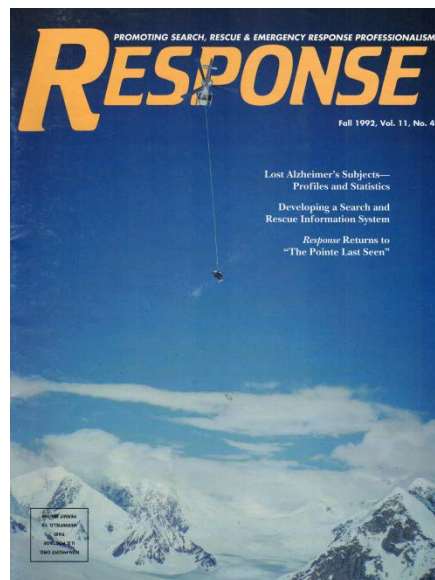
Section 1: Probability of Area (POA)

Lost Alzheimer's Subjects – Profiles and Statistics

Koester, R.J & Stooksbury, D.E

Response 11 (4) 20-26

1992

Lost Alzheimer's Subjects-Profiles and Statistics

By Robert I. Koester and David E. Stooksbury

Introduction

Incident commanders in missing person searches rely on lost person behavior profiles for the initial deployment of resources and development of objectives. To characterize the behavior of lost Alzheimer's subjects in the Middle Atlantic States, five years of search and rescue data from Virginia has been analyzed.

William Syrotuck was the first to systematically collect and analyze lost person behavior[1]. Barry Mitchell presents several subject profiles based on a large data set collected by the National Association for Search and Rescue.[2] Mitchell's work provides both behavior profiles and statistics to help predict the lost subject's location. The profiles include hunters, hikers, children (by age group), the mentally retarded, berry pickers and the elderly. These studies are incorporated into the major textbooks and field guides used by incident commanders.[3,4] More importantly, planners use this information during searches. Unfortunately, search subjects suffering from Alzheimer's disease have either been grouped with elderly subjects or been undocumented.

Early estimates of the prevalence of Alzheimer's disease was two million cases in the United States.[5] Current estimates are four million.[6] The increase is believed to be due to both an increase in awareness of the disease and an increase in medium age of the U .S. population. Regional demographics also greatly affect the percentage of Alzheimer's cases found in each state.

Alzheimer's disease is known as a disease of exclusion since it can only be diagnosed positively after the subject's death. However, Dementia of Alzheimer's Type (DAT) has been well characterized and can be documented with behavioral tests.[7-8] DAT is a chronic progressive disorder of unknown onset in which the affected individual suffers:

- A "loss of intellectual abilities of sufficient severity to impair their social or occupational functioning"
- Severely impaired memory
- Problems with abstract thinking, judgment, higher order cortical functioning or personality changes[9]

Initially, these changes are difficult to detect. However, they will eventually lead to such problems as wandering, pacing, aggression, irritability, withdrawal, fear and anxiety.

DA T is delineated into mild, moderate and severe categories.[1O] The earliest signs of DAT often appear during trips to unfamiliar surroundings. The patient is often visiting friends or family and becomes confused only a short distance from the residence. The patient with moderate DAT often appears normal even though they suffer from memory problems. Usually the caregiver relates stories about the patient previously be- coming lost, a decline in personal hygiene, an inability to carry out financial matters and an inability to remember recent conversations. Those patients suffering from severe DAT will clearly be recognized as suffering from "mental problems." Caregivers will usually report a patient with incontinence, an inability to feed or groom themselves, and a lack of recognition of loved ones.[11] In cases of severe DAT:

- 71% suffer from poor personal hygiene.
- 50% tend to wander.
- 50% become restless-
- 38% are easily agitated-
- 30% have hallucinations-
- 30% experience difficulty with incontinence.
- 29% experience falls.
- 29% become suspicious of those around them.

Four of these characteristics, wandering, agitation, poor hygiene and incontinence, significantly increase with further deterioration of the DAT patient. Among mild cases of DAT, 18% of the patients wander, while in severe cases wandering increases to 50%.[12] This particular trait has serious consequences when the patient wanders into a wilderness or rural location.

It is important to realize that 35% of DAT patients have a coexisting diagnosis.[13] The most common additional problems are depression (25%), overmedication, hypothyroidism, hyperparathyroidism, diabetes, acute infections and Parkinson's disease.[14] Most of these problems tend to decrease activity and the potential distance a DAT patient may travel.[15]

DAT subjects differ significantly from other lost subject behavioral profiles. Hikers, hunters and other groups venture into the woods with both a purpose and equipment. Therefore, the types of clues they leave often involve multiple physical objects. Containment is an effective technique in searches for hikers and hunters. The tactic relies upon the lost subject recognizing and following features such as a road, trail or string barrier. DAT subjects may simply wander into the woods and tend not to leave physical clues other than signs of passage and scent. The only other potential physical clues are the subjects' discarded clothing or pocket contents. DAT subjects may not recognize the value of such features or even recognize the fact they are lost

Materials and Methods

The Virginia Department of Emergency Services (DES) is responsible for coordinating search and rescue (SAR) activities throughout the state. In 1986, a new management system was introduced that utilizes selected operations personnel to 'handle all requests for SAR assistance.

Therefore, all SAR requests are handled by personnel involved in SAR education and operations. Additionally, it created a new record-keeping system and database.[16] This retrospective study begins in June 1986 with the first state recorded mission (VAOO1) and ends in June 1991 (VA234). Due to duplications in the numbering of some missions, 245 incidents are covered.

System Description. The DES SAR duty officer is responsible for alerting state field operational resources, coordination between the local law enforcement agency and state police, coordination with local emergency coordinators, coordination between state and federal resources, field support and data collection.

State field operational resources are tested by the independent Virginia Search and Rescue Council (VASARCO). VASARCO has representatives from all active statewide SAR resources. State resources include air scent dog teams, dog tracking teams, mounted horse teams, explorer scouts, management teams, ground teams, tracking teams, the Civil Air Patrol and government resources. The state peacetime disaster plan places responsibility with the local law enforcement agency if the local plan does not otherwise specify the role. The initial response from local law enforcement varies depending upon the locality. While some law enforcement officials contact DES immediately to request state resources, many localities will conduct search operations for six hours to several days before requesting state help.

To activate the system, a citizen reports the missing person to a local law enforcement agency, rescue squad or fire department. Once a request for state assistance is made, the initial response usually consists of an overhead management team, air scent dog teams, tracking dog teams, hasty teams and helicopters. After assessing the situation, the overhead team is responsible for requesting additional resources.

Criteria for Inclusion. Only searches issued a DES mission number are included in the relationship studies and the point last seen analysis. Five additional searches before 1986 and four additional searches after June **1991** are added to the clues, roadway crossings, techniques used, medical conditions and attraction analysis. Mission numbers are issued only when state SAR resources are dispatched to the incident. All data was collected from a combination of the DES Missing Person Reports, DES after Action Reports and Virginia SAR Council mission summaries. These reports generally are completed by the incident commander or a general staff member. Missing information is often collected later by the DES SAR officer. Copies of the original reports were furnished by DES.

The state data forms do not include information concerning the medical diagnosis of injured or dead subjects, clues discovered during the search, techniques used to locate the subject or whether the subject crossed any roads. Therefore, a review of state records, search team records and personal records of the incidents was performed.

Classification as a DAT missing person is based solely upon the caregiver's description of the subject. Incident commanders have no specific training to allow them to determine the validity of such claims. The data collection form has no specific question concerning a DAT description or mental status of the search subject. Therefore, it is completely voluntary for the compiler to fill in a DAT description in the "other pertinent information" blank. If the compiler did not mention Alzheimer's disease, dementia, senility or confused, the missing person was classified as either elderly (if over 60 years of age) or placed into another category (retarded, despondent, etc.).

Year	Total Searches	DAT Searches	%DAT
1987	33	1	3%
1988	40	4	10%
1989	49	8	16%
1990	54	9	16%

Data Coding. The information provided on the *state form* includes: state mission number, age and sex of subject, time the subject was last seen, date subject was last seen, type of location where last seen (nursing home, residence, etc.), air distance from subject last seen to where subject found, description of terrain where subject located and a brief summary of subject's medical condition.

The information recorded from *personal records* includes date, subject name, location, condition of subject, successful or suspended mission, field diagnosis of subject's medical condition, any verifiable clues located, terrain description of find location, whether the subject crossed or left roads and the search technique that located the subject.

Results

Twenty-nine (12%) out of 245 recorded state incidents involved possible DAT sufferers. This particular category was the largest in the data set. The other most prevalent search types included suicidal (12%) , children (11%) , hikers (10%), drownings (9%) and murders (9%) (figure 1). The drowning and murder cases usually reflect requests for dog teams. There has been an increase in the number of DAT searches and in the percentage of total search load (table 1). The increase in the median age of the U.S. population and an increased awareness of Alzheimer's disease are believed to be responsible for this increase.[17]

The medical condition of the DAT subjects after being found varied greatly. Eleven subjects (38%) required no medical attention (class one) and were able to be escorted out of the woods. Twelve subjects (41 %) required evacuation team (class two) (the forms do not always state the specific medical problem). Six subjects (21 %) were found deceased (class three). In searches for elderly subjects not suffering from DAT (n=10), six subjects were classified as class one (60%); one subject was class two (10%) due to hypothermia and dehydration; and three subjects (30%)

were found deceased (heart attack, drowning, unrecorded). There is no relationship between the age of the DAT subject and outcome (class) of the subject (figure 2).
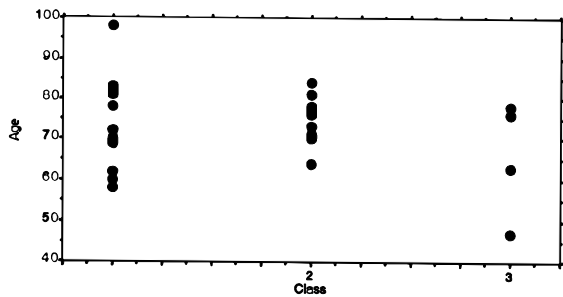

Figure 2: *Class vs. Age.*

Twenty-five (25) of the DAT searches have data on the subject's distance from the point last seen (PLS) .In all 29 searches, the subject was located by either the search effort or by others. The four missing data points represent a failure to complete the data form correctly. The mean distance from the PLS is 0.6 miles (1.0 km). The median distance is 0.5 miles (0.8 km) with a range of 0-2 miles (0-1.2 km) (figure 3). This can be compared to elderly cases without DAT where a mean distance from the PLS is 2.3 miles (3.8 km). The median distance is 2.5 miles (4.2 km) with a range of 0.1-5 miles (0.2-8.3 km) (table 2). There is no relationship between the DAT subject's age and distance from the PLS (figure 4). However, there is a positive relationship between the distance from the PLS and subject class (figure 5).

Most DAT subjects are last seen at either their own residence or a nursing home (table 3) .In addition, the five subjects spotted on a road initially departed from a nursing home or residence. The terrain the subject was located in was recorded in 24 cases. *The majority of subjects are found in drainages/creeks or heavy brush/briars* (table 4). With the three cases found in a house, two were found hiding in their own house and one traveled to a previous residence. In most searches, the subject is found wandering by nonsearchers and not by search teams. In many cases, the subject is located before trained searchers arrive on the scene. Sweep teams are the most successful search technique (table 5).

DAT subjects requiring evacuation (n=10) suffered from hypothermia (56%) and/or dehydration (44%). No hospital records were reviewed to support the field diagnosis. Deceased subjects (n=6) appeared to have succumbed to hypothermia (4) , drowned (2) or died from heart disease (1). Physical clues were located in only three searches (14%). These included broken branches leading to the subject's shoe, sugar packets taken from a cafeteria and a personal letter. *Fourteen subjects walked across a road* (67%), *three subjects entered the woods after walking on a road* (14%) *and four subjects did not cross any roads* (19%).

Discussion

The data characterizing missing persons as suffering from DAT was provided by caregivers during the investigative component of the search. Investigators within Virginia are suspicious of the potential of DAT in elderly subjects. The Lost Person Questionnaire, a standard data collection tool used on all state searches, prompts the investigator to pursue mental alterations. While several other conditions can cause dementia and therefore be confused with Alzheimer's disease, this has minimal impact on the usefulness of the collected data. During searches (by definition the subject is not present), a definitive classification as DAT is impossible unless previously made by a physician. This is particularly true of subjects who become lost in wilderness and rural settings who often belong to a lower socioeconomic group and receive less healthcare. [18] Therefore, search managers will almost always be unable to differentiate between dementia and DAT. If the predictive database (this study) potentially includes both groups, then this dilemma is controlled.

The data allows the development of a DAT subject profile. The subject usually disappears from their residence or nursing home. While not documented in this study, it is worth noting that it has been the principal investigator's personal observation on 25 searches for DAT subjects that almost all had become lost before. Generally, the family or local authorities had been able to locate the subject rapidly. This tendency to become lost is consistent with an increasing tendency to wander. Once the subjects become lost they are generally found close to the PLS. While the investigators have heard numerous reports of Alzheimer's subjects walking great distances (10-15 miles), no such case appeared in the Virginia caseload. As a larger data pool develops, the mean distance of 0.6 miles will almost certainly increase. However, the median distance of 0.5 miles may remain stable.

Statistic	DAT Searches	Elderly Searches
Table 2: Search Statistics for DAT and Elderly Searches		
Number of Searches	25	7
Mean Distance from PLS	0.6 miles	2.3 miles
Standard Deviation of Distance	0.5 miles	2.1 miles
Median Distance from PLS	0.5 miles	2.5 miles
Number of Subjects	29	10
Age of Subject	73.3	71
Standard Deviation of Age	9.9	8.2
Subjects Yelling for Help	0	0
Subjects Responding to Yells	0	0
Males	17 (59%)	6 (67%)
Females	12 (41%)	3 (33%)
Class 1 Find (Walked Out)	11 (38%)	6 (60%)
Class 2 Find (Evacuated)	12 (41%)	1 (10%)
Class 3 Find (Deceased)	6 (21%)	3 (30%)
25% Probability Zone	0.4–0.5 miles	
50% Probability Zone	0.3–0.6 miles	
80% Probability Zone	0.2–1.0 miles	
90% Probability Zone	0.0–1.1 miles	
96% Probability Zone	0.0–1.5 miles	

It is unknown if the subjects spend considerable time wandering or if they walk a fairly direct path. Following a path of least resistance is supported by the considerable number (63%) of DAT subjects found in drainage/creeks or brush/briars. This indicates they walked downhill. Another 25% of the subjects appear to have become stuck in thick brush or briars (a feature untrained searchers often avoid) *.Both terrain features indicate a scenario of the subject traveling a path of least resistance until they reach a creek or get stuck in briars.*

Based on the authors' personal search notes, subjects are often found a short distance off a road or other feature that is easily traveled. The possibility of following a direct path is also supported by a number of subjects who were found between the PLS and a target location (favorite place, former residence, etc.). A line drawn from the subject's residence and the PLS (if a later sighting occurred) often predicts where the subject can be found. The difficulty the incident commander faces is determining the potential target.

The age of the subject has no predictive value for the subject's survivability or distance found from the PLS. It would be worthwhile to investigate the relationship between the severity of DAT (mild, moderate, severe) with search outcome and distance found from the PLS. The relationship between the survivability of the subject and distance from the PLS can be easily explained. The search area and time required to find the subject grows exponentially as the radius increases. The longer the subject is exposed to the elements, the less their chance of survival. This relationship has little operational use since during a search the distance the subject is from the PLS is unknown.

Unfortunately, the data forms do not consistently provide information about the exact medical condition of the subject when found. If the subject was found deceased, the incident commander did not receive a copy of the autopsy or the autopsy did not specify the exact cause of death. In those subjects requiring evacuation, making a field diagnosis is often difficult. However, none of the data forms report trauma. The only indicated disorders included hypothermia, dehydration, drowning, heart disease and unknown. *Therefore, it appears DA T subjects are most likely to succumb to the environment and not to any injuries or pre-existing diseases*
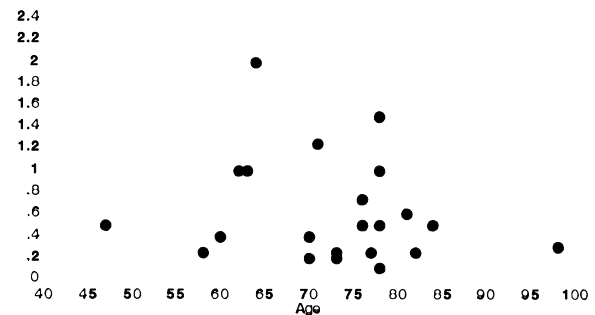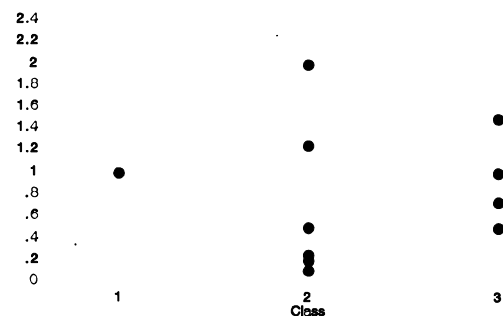

Figure 4: *Age vs. Distance Found From **PLS.***

Figure 5: *Class vs. Distance Found From PLS.*

An important aspect in redeploying resources and ultimately finding the missing subject is looking for and analyzing clues. The large percentage of searches without clues (86%) is most likely due to the fact that DAT subjects have no equipment, food or extra clothes to discard. Almost all subjects are found with all their clothes, so very few personal clues exist for searchers to find. All of the clues located required an active investigation to verify and determine their value. Resources capable of locating scent (dog teams) or passage (trackers) may playa critical role in locating the subjects.

Containment plays a small role in locating DAT subjects. Periodic road patrols still have value due to the number of DAT subjects located on roads (8%). Indeed, within Virginia the technique is seldom used. It is clear that DAT subjects will cross roads. In many of these cases the subject crossed two lane paved roads that are heavily traveled.

To better predict DAT missing subject behavior, a much larger pool of data is required. It is important to recognize the critical role that local terrain may have in distances covered. Virginia consists of a swampy tidewater region, rolling hills in a piedmont region and a heavily forested mountainous region. Numerous roads and paths crisscross most wilderness regions. An obvious need to better document the observations that DAT subjects have wandered previously, aimed for some target, crossed roads, generally traveled downhill, usually traveled only a short distance, easily bec4Ine stuck in briars and easily died or succumbed to environmental disorders must be pursued in larger national prospective studies.

Summary

- Subject leaves own residence or nursing home, possibly with last sighting on a roadway.
- Subject has previous history of wandering
- Coexisting medical problems that limit mobility are common.

Table 3 Point Last Seen (PLS)

Personal Home	9 (36%)
Nursing Home	9 (36%)
Roadway	5 (20%)
Relatives	2 (8%)

Table 4: Location of Find

Creeks/Drainages	9 (38%)
Bushes/Briars	6 (25%)
Open Field	4 (17%)
Roadway	3 (12%)
House	2 (8%)

Table 5: Successful Field Techniques

Non Searchers	10 (42%)
Sweep	6 (25%)
Scratch (Hasty)	3 (13%)
Air Scent Dog	3 (13%)
Helicopter	2 (8%)

- Subject will usually be found within 0.5 miles of point last seen.
- Subject usually found a short distance from a road.
- Subject usually found in creek or drainage and/ or caught in briars/bushes (63%).
- Subject will not cry out for help or respond to shouts.
- Subject will not leave many physical clues.

- Subject may attempt to travel to a former residence or to a favorite place.
- Subject usually succumbs to the environment (hypothermia, dehydration).

Suggested Search Techniques

- Early use of trackers at point last seen (PLS)
- Early use of tracking dogs at PLS and along roadways.
- Early deployment of air scent dog teams into drainages and streams, starting nearest PLS.
- Early deployment of hasty ground teams into drainages and streams nearest PLS.
- Thoroughly search the residence/nursing home and surrounding grounds and buildings; repeat every few hours.
- Cut for signs along roadways.
- Search heavy briars/bushes; remind field team leaders of this.
- Dog teams and ground sweep teams (in separate sectors) expanding from PLS.
- Air scent dog teams and ground sweep teams task 100 yards (initially) parallel to roadways.
- Search nearby previous homesites and the region between homesites and PLS.

Acknowledgements

End Notes

1. Syrotuck, W.1973. *A statistical analysis of lost persons in wilderness areas.* Westmoreland, NY: Arner Publications.

2. Mitchell, B. 1986. A summary of the National Association for Search and Rescue data collection and analysis program for 1980- 1985. Fairfax, VA: NASAR.

3. NASAR. 1987. *Managing the search function.* Fairfax, V A: NASAR.

4. NASAR. 1987. *Incident commander field hand- book: Search and rescue.* Fairfax, V A: NASAR.

5. Gruetzner, H. 1988. *Alzheimer's-A caregivers guide and sourcebook.* New York: John Wiley & Sons, Inc.

6. Evans, D., et al. 1989. Prevalence of Alzheimer's disease in a community population of older persons.JAMA 262:2551-6.

7. Folstein, M.R.; Folstein, S.; and McHugh, P.R. 1975. Mini-mental state: A practical method for grading the cognitive state of patients for the clinician.] *Psychiatric Res.* 12:189.

8. Blessed, G.; Tomlinson, B.; and Roth, M. 1968. The association between quantitative methods of dementia and senile change in the cerebral gray matter of elderly subjects. *Br.] Psychiatry* 114:797.

9. American Psychiatric Association. 1980. *Diagnostic and statistical manual-III.* Washington, DC: American Psychiatric Press.

10. Kahn, R., e\ al. 1960. A brief objective measure for the determination of mental status in the aged. *Am.*] *Psychiatry* 117:326- 328.

11. Reifler, B. 1983. Clinical aspects of Alzheimer's disease. *Modem Med. Canada* 38:17-20.

12. Teri, L.; Larson, E.; and Reifler, B. 1988. Behavioral disturbance in dementia of the Alzheimer's type.] *American Geriatrics Society* 36:1-6.

13. Reifler, B., et al. 1981. Treatment results at a multispecialty clinic for impaired elderly and their families.] *Am. Geriatric Soc.* 29:279.

14. Reifler, B.; Larson, E.; and Hanley, R. 1982. Coexisting cognitive impairment and depression in geriatric outpatients. *Am.] Psychiatry* 139:623.

15. Adams, R., and Victor, M. 1989. *Principles of neurology, 4th ed.* New York: McGraw-Hill.

16. Wilfong, R. 1987. Time frame for survival-minutes and counting-Virginia enhances search and rescue capabilities. *Lifeline* 11:2:10-13.

17. CDC Editorial Note. 1990. Mortalit;y patterns-United States-1987. *MMWR* , 39:193-6.

18. Rosenblatt, RA. 1991. The potential of the academic medical center to shape policy-Qriented rural health research. *Acad. Med.* 66:662-7.

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Behavioral Profile of Possible Alzheimer's disease Subjects in Search and Rescue incidents in Virginia

Koester, R.J & Stooksbury, D.E
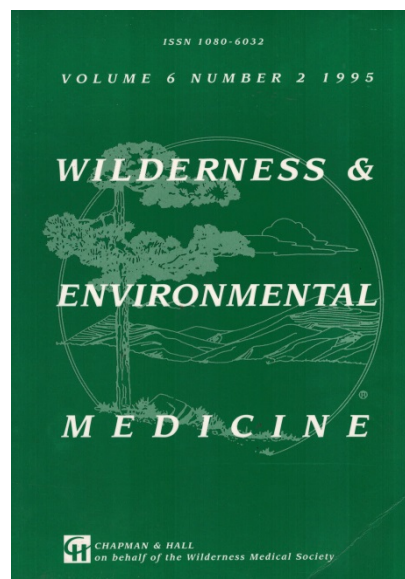
ORIGINAL ARTICLE

Behavioral profile of possible Alzheimer's disease patients in Virginia search and rescue incidents

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We performed a retrospective study of the behavior of lost dementia of Alzheimer's type (DAT) patients who became the subjects of organized search and rescue efforts. We compared the DAT patients' behavior to the behavior of elderly lost victims who possessed normal cognitive abilities. Data for both populations were from the Virginia Department of Emergency Services lost-subject database. We found that normal elderly individuals on average traveled a greater straight-line distance (2.56 km) from the point last seen (PLS) than did DAT patients (0.88 km). The median straight-line distance from the PLS was the same for both populations (0.8 km). The mortality rate for DAT patients was 19%. Mortality was caused by hypothermia, dehydration, and drowning. No fatalities were found among DAT patients when they were located within 24 h. A mortality rate of 46% was found for patients requiring more than 24 h to locate. This 24-h survivability window suggests that lost DAT patients require an immediate and aggressive search response.

Key words: wandering, Alzheimer's disease, lost person behavior, missing person, behavioral profile

Introduction

Our goals are to create a preliminary behavioral profile of lost dementia of Alzheimer's type (DAT) patients, to determine factors that impact survivability, and to create a database. Incident commanders in missing person searches rely on lost person behavior profiles and statistics for the initial deployment of resources, development of objectives, and predicting survivability. The major textbooks and field guides currently used by incident commanders combine both Alzheimer's individuals with elderly subjects or fail to give any numbers [1,2]. Unfortunately, search subjects suffering from Alzheimer's disease are grouped with elderly subjects or are undocumented.

Current estimates of Alzheimer's disease in the United States are 4 million, based on an estimated 10.3% of the population over the age of 65 [3]. In this scenario, 12–14 million Americans will be affected by the year 2040 [4]. The increase is believed to be due to an increase in awareness of the disease and an increase in the age of the US population [5]. Regional demographics also will affect the percentage of Alzheimer's cases found in each state. There appears to be a higher prevalence in rural areas [6] and among those with less

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education [7,8]. It is this particular subset of DAT patients that often results in search and rescue incidents.

Alzheimer's disease (AD) is a disease of exclusion, as it can currently be definitively diagnosed only after the patients' death. However, DAT [9] or probable AD is well characterized and can be presumed using behavioral tests [10–12]. Wandering as a feature of behavior significantly increases with further deterioration of the DAT patient. Among mild cases of DAT, 18% of patients wander, whereas in severe cases, wandering afflicts up to 50% [13]. Other studies that have made estimates of the prevalence of wanderers range from 12% to 39% [14,15]. One study reported 26% of a group of AD patients getting lost in the outdoors in a week [16].

Wanderers are distinguishable from nonwanderers by constant disorientation, inability to know when they are lost, better social skills, and more activity [17]. These traits have serious consequences when the patient wanders into a wilderness or rural location. Looking at several factors that affect survival in patients with DAT, only the severity of DAT, behavioral problems, and wandering or falling correlate to decreased longevity [18]. One law enforcement agency reported 4 deaths out of 450 separate episodes of critical wandering [19]. Nova Scotia's Emergency Measures Organization reported a mortality rate of 7 out of 15 among "walk-a-ways" (Alzheimer's, other senile dementia, mentally retarded, psychosis). All fatalities were attributable to hypothermia [20]. In another study, 6 out of 29 patients died when search and rescue groups responded only after law enforcement search attempts were unsuccessful. Deceased patients appeared to have succumbed to hypothermia or to have drowned. Twelve patients were found alive, but required evacuation. Based on field diagnosis, all the patients suffered from hypothermia and/or dehydration. DAT patients have usually wandered before, are generally unresponsive even when uninjured, leave few physical clues, and wander across roads [21].

Materials and methods

The Virginia Department of Emergency Services (DES) is responsible for coordinating search and rescue (SAR) activities throughout the state. In 1986, DES introduced a new management system that uses selected operations personnel to handle all requests for SAR assistance. The new management system initiated a record-keeping and database system [22]. This retrospective study looks at data from June 1986 with the first state-recorded mission to January 1992. Two hundred ninety-five incidents are covered.

Criteria for inclusion

Only searches issued a DES mission number were included in our analysis. Mission number issuing occurs when DES dispatches state SAR resources to an incident. The DES Missing Person Reports, DES After Action Reports, and Virginia SAR Council Mission Summaries were the sources for all data. The incident commander or a general staff member generally completed these reports. The DES SAR office often completed missing information later. The SAR office furnished us copies of the original reports.

The caregiver's description of the patient was the sole basis for classification of a subject as a DAT patient. The patient had to be older than 40 years with the possible age of onset of dementia between 40 and 90 years of age. If there was a history of mental retardation or psychosis (before onset of dementia), the subject was excluded. Further classification of

the missing person as potentially suffering from degenerating dementia was made by the primary investigator based solely on the information provided on the data forms. Incident Commanders have no specific training to allow them to determine the validity of such claims. The data collection form has no specific question concerning a DAT description or mental status of the search patient. Therefore, it is completely voluntary for the compiler to fill in a DAT description in the "other pertinent information" blank. If the compiler did not mention Alzheimer's disease, dementia, or senility, the missing person was classified as either elderly (if > 60 years of age) or placed into another category (retarded, despondent, etc.). No attempt was made to isolate other potential causes of dementia.

Data coding

If the information provided on the state form leads to a classification of DAT, the following information is collected: state mission number, age, sex, race, time the patient was last seen, date patient was last seen, type of location where last seen (nursing home, residence, etc.), straight-line distance from patient last seen location to where patient was found, time patient located, search technique that located patient, description of terrain where patient was located, and a brief summary of patient's medical condition. We entered the data (handwritten forms) into a Microsoft Excel 4.0 spreadsheet [23].

Statistical methods

We performed the statistical analysis using the software package, StatView 512+ [24]. For descriptive purposes and for future reference, we present the mean, standard deviation, and standard error within categories. Analysis of variance (ANOVA) was performed with significant F-values being reported. The level of significance was the traditional $p < 0.05$. If the ANOVA was significant, the conservative Scheffe's test for differences between specific means was performed [25]. We report only significant F-values.

Results

Forty-two (15%) of 295 recorded state incidents involved possible DAT sufferers (Fig. 1). One search involved two DAT patients who remained together. This particular category was the largest in the data set. In all 42 searches, the search effort or others located the patient. The other most prevalent search types included suicidal (12%), children (12%), drowning (11%), murders (9%), and hikers (8%). The drowning and murder cases usually reflected requests for dog teams only. The DAT searches occurred over a 5-year period. There has been an increase in both the numbers of DAT searches and the percentage of total search load (Table 1).

We divided the patients into three classes based on their medical condition at the time of the find. Team leaders with basic first-aid training made the field classifications summarized below.

Class One: Require no medical treatment and can walk out without assistance
Class Two: Require medical assistance and an evacuation
Class Three: Dead on arrival

The medical condition of the DAT patients after being found varied greatly. Twenty patients (47%) could be escorted back to their residence and required no medical attention (class one). Fifteen patients (35%) required an evacuation team (class two). The
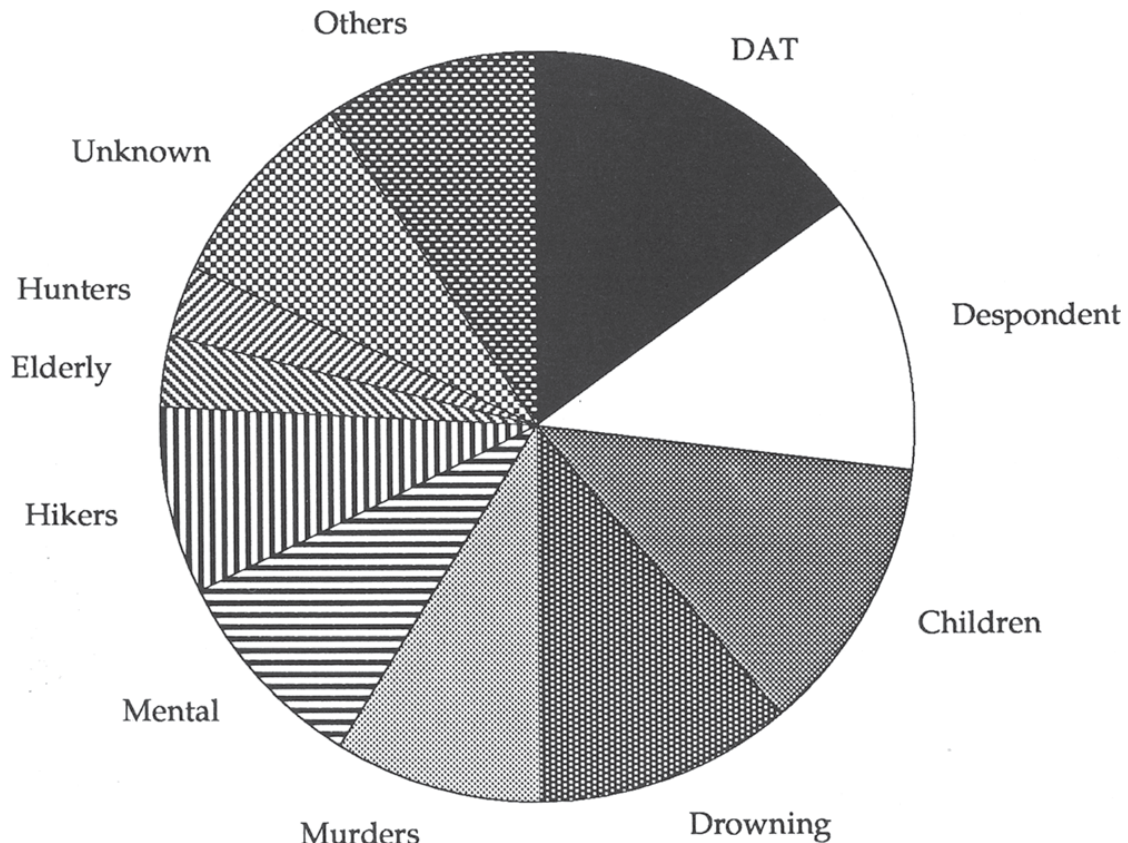
Fig. 1. Breakdown of Virginia searches.

state forms did not always specify the specific medical problem and the field diagnoses were not verified by hospital records. Experienced emergency medical technicians (EMTs) with supplemental training in wilderness disorders made the field diagnoses. DAT patients requiring an evacuation ($n = 13$) suffered from hypothermia (67%) and/or dehydration (33%). In two cases, patients were field diagnosed as suffering from both disorders. All evacuated patients survived and were discharged from the hospital. Eight patients (19%) were found deceased (class three) and appeared to have succumbed to hypothermia ($n = 6$) or drowned ($n = 1$). For one patient, the cause of death was neither determined nor recorded. No evacuated or deceased patient demonstrated any trauma based on field evaluation. In searches for elderly subjects not suffering from DAT ($n = 10$), six subjects

Table 1. Total searches and DAT searches

Year	Total searches	DAT searches	% DAT
1986	32	5	16
1987	33	1	3
1988	40	4	10
1989	49	8	16
1990	54	9	16
1991	87	16	18

Table 2. Elderly versus Alzheimer's distance traveled

	Number	Median (km)	Mean (km)	Std. dev.	Std. error
Alzheimer's	37	0.8	0.88	0.74	0.12
Elderly	11	0.8	2.56	3.05	0.92
F-value = 9.92					

were class one (60%); one subject was class two (10%) due to hypothermia and dehydration; and three subjects (30%) were deceased (heart attack, drowning, unrecorded).

There is no relationship between the age of the DAT patient and outcome (class) of the patient. There is also no relationship between the age of elderly patients and the outcome of the subjects.

Thirty-seven of the DAT searches and all 11 elderly searches had the patient's distance from the point last seen (PLS) recorded. The missing data points represent a failure to complete the data form correctly. The mean distance the DAT patient was found from the PLS is 0.9 km (0.6 mile). The median distance is 0.8 km (0.5 mile) with a range of 0–2.4 km (0–1.5 miles). For elderly cases without DAT, the mean distance found from the PLS is 2.6 km (1.6 miles). The median distance is 0.8 km (0.5 miles) with a range of 0–12.8 km (0–8.0 miles) (Table 2). There is no relationship between the DAT patient's age and distance from the PLS, or the distance from the PLS and patient class (Table 3).

There was a significant increase in morbidity and mortality as the total time elapsed to find the patient increased (Table 4). There was also a significant increase in morbidity and mortality as the time increased from when trained SAR resources were notified and the patient was located (Table 5). The one uninjured DAT patient located after a considerable delay was in an uninhabited former residence. Among those patients located within 24 h of last being seen, no deaths occurred (Table 6). In two cases, the search was suspended (on days 4 and 7) without the patient being found. These searches are not included in the analysis, though the body was eventually located within the search area. Most DAT patients were last seen at either their own residence or a nursing home (Table 7). In addition, all eight patients spotted on a road initially departed from a nursing home or residence. The terrain in which the patient was located was recorded in 36 cases (Table 8). The majority of patients were in drainages/creeks or heavy brush/briars. In the 4 cases in which patients were in a house, 2 were hiding in their own house and 2 traveled to a previous residence. In most searches, the patient was not found by search teams but found

Table 3. Distance DAT patients found from PLS by class

	Number	Median (km)	Mean (km)	Std. dev.	Std. error
Class 1	15	0.6	0.84	0.70	0.18
Class 2	14	0.6	0.81	0.85	0.23
Class 3	8	0.9	1.10	0.34	0.23

Table 4. DAT patients' class by total time to locate

	Number	Mean (h)	Std. dev.	Std. error
Class 1	18	19.8	31.62	7.45
Class 2	15	22.5	14.96	3.86
Class 3	5	102.7	38.42	17.18
Total $F = 19.50$				
Scheffe F	1 vs. 2	NS (0.41)		
	1 vs. 3	18.07		
	2 vs. 3	16.20		

wandering by others. This includes searches where the state issued a mission number but the patient was found before the arrival of search and rescue resources. Sweep and scratch (hasty) teams are the most successful organized technique used to find DAT patients (Table 9).

Discussion

During the investigative component of the search, the caregivers provide the data characterizing missing persons as suffering from DAT. Investigators within Virginia are suspicious of the potential of DAT in all elderly subjects. The Lost Person Questionnaire, a standard data collection tool used on all state searches, prompts the investigator to pursue mental alterations. We did not use rigid criteria for inclusion as a dementia of Alzheimer's type in any of the cases. There was no follow-up behavioral testing due to both the circumstances of a search and the retrospective nature of this study. While several other conditions can cause dementia and, therefore, be confused with Alzheimer's disease (AD) [26], this has minimal impact on the usefulness of this study for search planners. During searches (by definition the subject is not present), a definitive classification as DAT is impossible unless it was made previously by a physician. Most persons with AD receive

Table 5. DAT patients' class by time for SAR resources to locate

	Number	Mean (h)	Std. dev.	Std. error
Class 1	18	9.9	9.66	2.28
Class 2	15	12.1	7.55	1.95
Class 3	6	70.3	39.19	16.00
Total $F = 32.03$				
Scheffe F	1 vs. 2	NS (0.68)		
	1 vs. 3	29.27		
	2 vs. 3	25.92		

Table 6. Survivability

	$< 24\,h$	$> 24\,h$	$> 48\,h$	$> 72\,h$
Class 1	16 (64%)	2 (15%)	1 (13%)	1 (17%)
Class 2	9 (36%)	5 (39%)	2 (25%)	0 (0%)
Class 3	0 (0%)	6 (46%)	5 (62%)	5 (83%)

care from a primary care physician or are not recognized as having the condition. Because most primary care physicians fail to use cognitive status tests [26], they only identify correctly 58% of the cases as possible dementia [27]. This is particularly true of patients who become lost in wilderness and rural settings, who often belong to a low socioeconomic group and receive less health care. Even after locating the patient, possible hypothermia and/or dehydration would confound the administration of a simple diagnostic test such as the Mini-Mental State Exam (MMSE). Even a well-constructed prospective study would face difficulties, because it would still be impossible to test deceased patients and difficult to follow-up on patients who required evacuation. Therefore, search managers will almost always be unable to differentiate between dementia caused by other reasons and DAT. Even establishing that the patient suffers a true dementia may be a challenge. If the predictive database (this study) potentially includes both groups, then this dilemma is controlled. However, future attempts to differentiate between Alzheimer's, Multi-infarct, or Parkinson's dementia may lead to more precise patient profiles.

The distribution of search incidents for the different patient profiles reflects two major study factors. In Virginia, state mission numbers are only given after local law enforcement efforts have failed to locate the subject. In addition, the terrain and number of trails and roads make it difficult to become truly lost in the state. In fact, the profiles of DAT, mentally retarded, despondent, psychotic, and children all represent decreased spatial and/or cognitive abilities and together account for 47% of the state case load. Using current estimates of the prevalence of AD [3] and the 1990 population of elderly within Virginia [28], an estimated 68 500 Virginians suffer from DAT. This represents 1% of the population, compared to the 15% of all searches for DAT patients. The data allow development of a preliminary DAT patient profile. Patients usually disappear from their private residence or a nursing home. Once a patient becomes lost, he is usually found close to the PLS.

These data support the few anecdotal case studies reported in the literature [29,30]. In addition, they support the personal experience of the authors, reported elsewhere [21]. This finding is somewhat surprising, considering DAT sufferers may be healthier than

Table 7. Place last seen

Personal home	15 (39%)
Nursing home	12 (32%)
Roadway	8 (21%)
Relatives	2 (5%)
Camping	1 (3%)

Table 8. Environment of find

Bushes/briars	13 (33%)
Creeks/drainages	10 (28%)
Open field	5 (14%)
Roadway	5 (14%)
House	4 (11%)

other age controlled elderly [31] and by definition only suffer initially from a loss in cognitive domains [12]. A possible explanation is that moderate DAT patients showed shorter step length, lower gait speed, lower stepping frequency, greater step-to-step variability, and greater sway path [32]. Although the investigators have heard many reports of Alzheimer's patients walking great distances (10–15 miles), no such case appeared in the Virginia case load. As a larger data pool develops, the mean distance of 0.9 km will almost certainly increase. However, the median distance of 0.8 km may remain stable. It is unknown if patients spend considerable time wandering or if they walk a fairly direct path. The considerable number (28%) of DAT patients found in drainages or creeks supports the "following of a path of least resistance" hypothesis. This indicates that most persons walked downhill. Another 33% of the patients appeared to have become stuck in thick brush or briars (a feature untrained searchers often avoid). Together (61%), both terrain features indicate a scenario of the patient traveling a path of least resistance until they reach a creek or get stuck in briars.

The age of the patient had no predictive value in the patients' outcome (class) or distance from the PLS. This corresponds well to studies that show that age has no relationship with cognitive or behavioral disturbance or the rate of progression of DAT [33,34]. It would be worthwhile to investigate the relationship between the severity of DAT (mild, moderate, severe) with search outcome and distance from the PLS. The relationship between the class of the patient and distance from the PLS previously reported as significant [21] showed no relationship in this study. This relationship has little operational use, since during a search, the distance the patient is from the PLS is unknown.

The relationship between patients' outcome and the time elapsed to locate has clear implications. Family members must not hesitate to contact law enforcement officers when a DAT patient becomes missing. In turn, once law enforcement officials have determined the need for a search effort, they must not hesitate to activate specialized SAR resources. These resources include management teams, trackers, tracking dogs, air-scent dogs, helicopters, and clue aware scratch (hasty) teams. The 24-h window for optimal results requires an immediate and aggressive response from all parties concerned.

Table 9. Successful field techniques

Nonsearchers	10 (33%)
Sweep	8 (24%)
Scratch (hasty)	7 (12%)
Air-scent dog	4 (12%)
Helicopter	4 (12%)
Road patrol	1 (3%)

Unfortunately, the state forms do not consistently provide information about the exact medical condition of the patient when found. If the patient was deceased, the Incident Commander did not receive a copy of the autopsy or the autopsy did not specify the exact cause of death. In patients requiring evacuation, making a field diagnosis is often difficult. However, none of the data forms report trauma. This is rather surprising, considering the large number of DAT patients (29–36%) that experience serious falls [13,16]. In fact, falls are more likely to occur in DAT patients than in elderly controls [35]. The lack of any falls may be due to either the small data base, lack of autopsy results, or perhaps the difficulty in detecting evidence of a fall in a hypothermic patient. The only recorded disorders included hypothermia, dehydration, drowning, and unknown. Therefore, it appears DAT patients are most likely to succumb to the environment and not to any injuries or preexisting diseases.

To better predict DAT missing patient behavior requires a much larger data pool. As Alzheimer's disease continues to increase in prevalence, it unfortunately will become easier to collect data. It is important to recognize the critical role local terrain may have in distances covered. Virginia consists of a swampy tidewater region, rolling hills region, and a heavily forested mountainous region. We expect that the distances traveled by DAT patients will be greater in less densely vegetated regions. Numerous roads and paths crisscross even the most rugged wilderness regions, limiting the distance that one can travel without crossing a road. An obvious need to expand the database on a national basis in various types of terrain under more controlled prospective conditions must be pursued. More rigid criteria for classifying patients as DAT or possible dementia should be considered.

Acknowledgments

References

1. NASAR. *Managing the Search Function.* Fairfax, VA: NASAR, 1987.
2. NASAR. *Incident Commander Field Handbook: Search and rescue.* Fairfax, VA: NASAR, 1987.
3. Evans, D., Funkenstein, H.H., Albert, M.S. *et al.* Prevalence of Alzheimer's disease in a community population of older persons. *JAMA* 1989; **262**(18), 2551–6.
4. Evans, D.A., Scherr, P.A., Cook, N.R. *et al.* Estimated prevalence of Alzheimer's disease in the United States. *Milbank Mem Fund Q* 1990; **68,** 2267–89.
5. CDC Editorial note: Mortality Patterns–United States–1987. *MMWR* 1990; **39**(12), 193–6.
6. Rocca, W.A., Bonairto, S., Lippi, A. *et al.* Prevalence of clinically diagnosed Alzheimer's disease and other dementing disorder: a door-to-door survey in Appignano, Macerata Province, Italy. *Neurology* 1990; **10,** 626–31.
7. Durtigues, J., Gagnon, M., Michel, P. *et al.* The Paquid research program on the epidemiology of dementia. Methods and initial results. *Revue Neurolog.* 1991; **117**(3), 225–30.
8. Fratiglioni, L., Grut, M., Forsell, Y. *et al.* Prevalence of Alzheimer's disease and other dementias in an elderly urban population: relationship with age, sex, and education. *Neurology* 1991; **11**(12), 1886–92.
9. American Psychiatric Association. *Diagnostic and Statistical Manual–III.* Washington, DC: American Psychiatric Press, 1980.
10. Folstein, M.R., Folstein, S. and McHugh, P.R. Mini-Mental state: A practical method for grading the cognitive state of patients for the clinician. *J Psychiat Res* 1975; **12,** 189.

11. Blessed, G., Tomlinson, B. and Roth, M. The association between quantitative methods of dementia and senile change in the cerebral gray matter of elderly subjects. *Br J Psychiatry* 1968; **114,** 797.

12. McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D. and Stadlan, E.M. Clinical diagnosis of Alzheimer's disease: report of the NINCDS–ADRDA Work Group under the auspices of Department of Health and Human Services Task Force of Alzheimer's Disease. *Neurology* 1984; **34,** 939–44.

13. Teri L., Larson, E. and Reifler, B. Behavioral disturbance in Dementia of the Alzheimer's Type. *J Am Geriatrics Soc* 1988; **36,** 1–6.

14. Cohen-Mansfield, J., Werner, P., Marx, M. and Freedman, L. Two studies of pacing in the nursing home. *J Gerontol* 1991; **46**(3), M77–83.

15. Cooper, J., Mungas, D. and Weiler, P. Relation of cognitive status and abnormal behaviors in Alzheimer's disease. *J Am Geriatrics Soc* 1990; **38,** 867–70.

16. Baumgarten, M., Becker, R. and Gauthier, S. Validity and reliability of the Dementia Behavior Disturbance Scale. *J Am Geriatrics Soc* 1990; **38,** 221–6.

17. Dawson, P. and Reid, D.W. Behavioral dimensions of patients at risk of wandering. *Gerontologist* 1987; **27**(1), 104–7.

18. Walsh, J.S., Gilbert Welch, H. and Larson, E.B. Survival of outpatients with Alzheimer-type dementia. *Ann Intern Med* 1990; **113**(6), 429–34.

19. Butler, J.P. Window of wandering. *Geriatric Nursing* 1991; September/October.

20. Hill, K. Predicting the behavior of lost persons. *NASAR Conference Proceedings.* Fairfax, VA: NASAR, 1991.

21. Koester, R.J. and Stooksbury, D.E. Lost subject profile for Dementia of Alzheimer's Type in Virginia. In *National Association for Search and Rescue Conference Proceedings.* Fairfax, VA: NASAR, 1992.

22. Wilfong, R. Time frame for survival–minutes and counting–Virginia enhances search and rescue capabilities. *Lifeline* 1987; **11**(2), 10–3.

23. Microsoft. *Excel 4.0* [computer program] Redmond, WA: Microsoft Corporation, 1992.

24. Cuneo, M., Feldman, D.S., Jr., Hofmann, R. and Simpson, J. *StatView 512+* [computer program]. BrainPower Inc., Calabasas, CA: 1986.

25. Snedecor, G.W. and Cochran, W.G. *Statistical Methods.* 7th ed. Ames, IA: Iowa State University Press, 1980.

26. Somerfield, M.R., Weisman, C.S., Ury, W. *et al.* Physician practices in the diagnosis of dementing disorders. *J Am Geriatrics Soc* 1991; **39,** 172–5.

27. O'Conner, D.W., Pollitt, P.A., Hyde, J.B. *et al.* Do general practitioners miss dementia in elderly patients? *Br Med J* 1988; **297,** 1107–10.

28. 1990 Census Summary Data Files–Virginia [Computer Laser Optical Disk STF1A] MS-DOS Version. U.S. Department of Commerce, Bureau of the Census, Data User Services Division, Vol. 1, 1991.

29. Burnside, I.M. Wandering behavior. In: Burnside, I.M., ed. *Psychosocial Nursing Care of the Aged.* 2nd ed. New York: McGraw-Hill, 1980; 298–309.

30. Hindlian, N.S. Case histories of wandering. *Am J Alzheimer's Care Related Disorders Res* Jan/Feb. 1988; 38–9.

31. Wolf-Klein, G.P., Silverstone, F.A., Brod, M.S. *et al.* Are Alzheimer's patients healthier? *J Am Geriatric Soc* 1988; **36,** 219–24.

32. Visser, H. Gait and balance in senile dementia of Alzheimer's type. *Age Aging* 1983; **12,** 296–301.

33. Burns, A., Jacoby, R. and Levy, R. Progression of cognitive impairment in Alzheimer's disease. *J Am Geriatrics Soc* 1991; **39,** 39–45.

34. Ortof, E. and Crystal, H.A. Rate of progression of Alzheimer's disease. *J Am Geriatrics Soc* 1989; **37,** 511–4.

35. Morris, J.C., Rubin, E.H., Morris, E.J. and Mandel, S.A. Senile Dementia of the Alzheimer's Type: An important risk factor for serious falls. *J Gerontol* 1987; **42**(4), 412–7.

The Lost Alzheimer's and Related Disorders Subject: New Research and Perspectives

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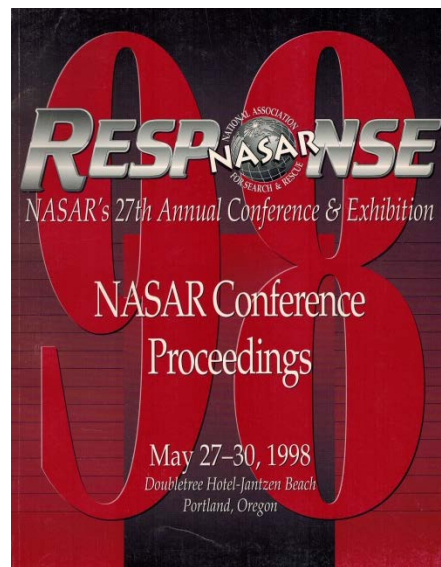
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The Lost Alzheimer's and Related Disorders Search Subject: New Research & Perspectives

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Introduction:

Wandering among the elderly, especially those suffering from possible Alzheimer's Disease and Related Disorders (ADRD)[1], has only recently begun receiving much attention. Possible Alzheimer's and Related Disorders includes Alzheimer's Disease and the less well known dementia causing disorders of Multi-Infarct Dementia, Parkingston's Dementia, Symptomatic Hydrocephalic, Korsakoff's Syndrome, Pick's Disease, Huntington's Disease, and Spongiform Encephalopathy. However, almost all studies have focused how these disorders cause wandering within the walls of an institution.[2,3,4] Many other papers mention wandering, but only as a behavioral disturbance,[5,6] management challenge in an institutional setting,[7] or as a correlation with further loss of cognitive ability.[8] Several other articles provide institutional care providers strategies for managing the wanderer.[9,10,11] The emerging importance of wandering and dementia is evidenced by the first time symposia addressing the problem at the American Gerontological Society.[12]

Little research has looked at wandering beyond the walls of the institution or residence. Anecdotal case studies are recorded in the literature by Burnside[4] and Hindlian.[13] Butler and Barnett report one critical wanderer per year for every 1000 persons over the age of 65, resulting in four deaths in 450 episodes in one county.[3] They did not provide any information that would aid search planners. A critical wanderer is defined as anyone with dementia who has wandered away (disappeared of their own free-will) from their caregiver. This definition characterizes critical wandering from the perspective of the caregiver, who is available to search and rescue investigators, unlike the missing subject. Nova Scotia's Emergency Measures Organization reported a mortality rate of 7 of 15 (47%) among "walkaways."[14] Hill has updated these figures with seven additional cases and the mortality rate was stable at 45%[15]. However, both studies included mentally retarded and psychotic subjects which obscures characterizing elderly dementia subjects, especially considering the small number (n= 15, 22) in the studies. Silverstein and Salmons in a study of 463 Safe Return registrants in Massachusetts found 72% of wanderers are repeat wanderers, caregivers search themselves preferring not to call for assistance, the police are called in 50% of the cases, and 69% of wandering cases are associated with severe consequences[16]. Koester and Stooksbury in a preliminary investigation of critical wanderers with Dementia of Alzheimer's type noted lost subjects have usually wandered before, are generally unresponsive even when uninjured, leave few physical clues concerning their location, often attempt to travel to a former residence, and they will wander across roads.[17] This study has been cited frequently in the Search and Rescue Community, including primary SAR textbooks[18,19]. However, it fails to take in account regional/topographical differences and may be misleading to non-researchers. A follow-up investigation, also by Koester and Stooksbury found in search and rescue incidents nine of forty-two (21%) of Dementia of Alzheimer's Type (DAT) subjects were found deceased

due to hypothermia, dehydration, or drownings. <u>All subjects found within 24 hours of disappearance survived while only 54% of those requiring greater than 24 hours survived.</u> DAT subjects were usually located (89% of all cases) within one mile (1.2 km) of the point they were last seen. If the wanderers were not found on the road itself (14%), they are usually found in a creek/drainage (28%), and/or caught in briars/bushes (33%).[20] Koester and Stooksbury's original studies were retrospective, used a loose criteria for determining dementia, relied upon field investigators with no training in Alzheimer's related disorders, collected a small sample size (n= 42), and only collected information from Virginia.

Growing Problem

The prevalence of critical wanderers can be expected to grow. The increase is believed to be due to both an increase in awareness of AD and an increase in the age of the U.S. population.[21] Using the incident rate of one critical wanderer per year per 1,000 persons over the age of 65,[3] the expected total of critical wanderer incidents reported to local law enforcement comes to 31,000 cases a year. Regional demographics will also greatly affect the percentage of Alzheimer's cases found in each state. Indeed there appears to be a higher prevalence in rural areas[22] and among those with less education.[23] It is this particular subset of DAT patients that often results in SAR incidents. Koester and Stooksbury found an increase in the number and percentage of searches for DAT patients.[20]

Severity

One of the most important characterizing features of dementia is its severity. Those with severe dementia might travel shorter distances, demonstrate non-goal directed behavior, and have shorter survivability time-frames than those with mild dementia. However, no studies have addressed this issue for critical wanderers.

Determining the severity and even the presence of dementia may present a considerable challenge in search and rescue incidents. During the search effort the subject by definition is not present. Therefore, the administration of a test battery[24] or use of the NINCDS-ADRDA criteria[1] is not possible. Furthermore, any tool developed must be easy for law enforcement and search investigators to use. In order to determine the severity of dementia during an incident a search investigator must rely upon information provided by informants (family or non-kin). Fortunately, tools have been developed that allow an investigator to obtain information from caregivers. A more demanding set of activities is incorporated into the instrumental ADL scales.[25,26] These tools are known instrumental activities of daily living (IADL). They gather information on the subjects ability to carry-out daily activities such as finances, hygeine, and navigation. IADLs also have strong correlations with MMSE scales.[27] The use of appropriate test in prospective studies will allow the collection of information relating the severity of the dementia with search behaviors and outcomes.

Mechanism of Lost Wanders

Alzheimer's Disease (AD) is known as a disease of exclusion since it can only be diagnosed positively after the subject's death.[28] Autopsy shows neuritic plaques and neurofibrillary tangles are found in greater numbers in the neocortex, hippocampus, and amygdala in Alzheimer's disease.[29] Granulovacuolar degeneration and Hirano bodies are also found, but almost entirely in the hippocampal formation.[30] The hippocampal formation is an integral component of several forebrain neural systems thought to play a role in memory processes.[31] AD causes the destruction of afferents and efferents which functionally isolates the hippocampus from the other cortical and subcortical areas known to be important for memory.[32] The hippocampus may also be the site of true allocentric spatial learning.[33] Place cells within the hippocampus

provide a spatial topography of a particular environment.[34] One may hypothesize that in severe dementia where the hippocampus has been completely disassociated from the cortex the wanderer may have no access to spatial maps (both long term and short term). This may lead to non-goal or aimless wandering or at least no discernable goal to an outside observer. In more mild cases of dementia the patient may still have access to spatial maps, can begin moving to a target location, but then become easily disoriented. It has already been shown that wandering significantly increases with further deterioration of the AD patient. Among mild cases of AD, 18% of the patients wander, while in severe cases, wandering increases to 50%.[5] Other studies have made estimates of the prevalence of wanderers ranging from twelve to thirty-nine percent.[35] Another study reported twenty-six percent of AD patients getting lost in the outdoors in the preceding week.[36] If a relationship is found between severity of dementia and the type of wandering, this information may greatly assist search planners. The pathophysiology of Alzheimer's Disease has been recently linked to cerebrovascular accidents along with Multi-Infarct Dementia[37,38].   It is possible the location, type, and size of brain lesions may be linked to laterally of wandering, direction of vector departure (from initial direction of travel), and type of wandering.   If a relationship is found between distance traveled and severity of dementia or the type of wandering, this information may greatly assist search planners.

Defining a Search Area

Search planners rely heavily on lost person behavior profiles and statistics for the initial deployment of resources and development of search objectives.   Modern search theory involves a four step process to determine the deployment of search teams. The search area is initially defined by the theoretical distance the subject could have traveled since being last seen. Since this area grows exponentially as time passes (especially if transportation is available) the theoretical area is not usually useful in limiting the search area. Next search planners limit the size of the search area by the use of empirically derived statistics that give probabilities for distanced traveled zones. These statistics have the greatest impact upon actual search planning. These boundaries are further limited by any geographical features that may make travel impossible or unlikely. Finally, analysis of the subject's behavioral profile, past incidents, and investigation delineate the most likely area. Subject behavior profiles and survivability statistics are also used throughout the search and help with the always difficult decision of when to suspend the mission. Unfortunately, no data gives guidance to search planners to help predict who may travel further than 94% zones (statistical outlier). While, all the major textbooks and field guides used by search planners and law enforcement officials incorporate statistical and behavioral information,[18,19] elderly search subjects suffering from dementia have been grouped with all elderly subjects.[39] This information is critical in rapidly locating the subject with the most efficient types of resources, when the chances of survival are the highest.

Straight Line Hypothesis

Identifying behavioral patterns can also assist search planners attempting to decide how to search for a missing critical wanderer. The working hypothesis for their overall behavior is they wander in a basically straight line until they get stuck in some type of barrier. A similar rationale is seen in recommendations to create barriers in institutional settings in order to reduce critical wandering.   Preventing exiting by placing a yellow strip of plastic across the door, painting the exit doors the same colors as walls, covering doors with curtains or movable screens, or placing mirrors on doors all depend upon a physical or mental barrier.[40]   The critical wandering may be seemingly random or it may be goal seeking. This is in agreement with several other studies

describing wandering within an institution. It is not uncommon to locate the subject in or heading to a former residence.[17] If a direction of travel is obtained at the point the subject is last seen it serves as an excellent predictor of the subjects location. Search planners from California have found this to be true within 10 degrees of the last sighting.[41] However, search teams in Louisiana report a general circle pattern.[42] Hebard also reports in the general press a circle pattern dependent upon being left or right handed[43]. Bartlow reports a ping-pong pattern of course alterations upon contact with travel barriers[44]. No data or studies were presented for the circle or ping-pong patterns cited. Silverstein and Salmons data found no difference in the direction traveled between right or left handed subjects.[16] Koester and Stooksbury also reported the straight line observation without supporting data. However, much more data needs to be collected and regional factors need to be considered. They also reported as the critical wanderer travels they will cross over roads (67% of the cases) until they get stuck in brush (25%) or in a drainage (38%). Another important undocumented observation is the distance they travel once they leave or cross a road is usually small. Unfortunately, no numbers have been collected to quantify this key planning factor. Critical wanderers once they are lost appear to leave few clues and seldom seek help (shout or signal). Only three cases of physical clues have occurred out of 43 searches. In none of these searches did the critical wanderer call out for help.[17] In fact their behavior may be described as evasive. This may be due to previous hallucinations or suspiciousness common among DAT patients.[5]

Weather and Climate

Weather and climate should have a major impact on both survivability and the frequency of wanderers. In addition, predicting a season or time of year when critical wandering increases can be important in developing prevention programs. No studies have answered this question. Synder et al make an undocumented observation that wandering increases after a cold spell.[2] Koester and Stooksbury noted experienced search mangers have made the same observation.[18] Furthermore, they showed the incidence of searches generally increased with warmer weather and decreased during cooler weather. Due to the small sample size no conclusions could be drawn. No studies have looked at how season affects survivability. However, the mortality rate of critical wanderers in Nova Scotia was 47% while it was only 22% in Virginia.[14] Therefore, we predict the colder weather will lead to a higher mortality rate. If this relationship is shown to be valid, survivability tables must be adjusted to reflect current and past weather conditions. Temperature, precipitation, wind, and humidity influence environmental disorders and are potential factors in creating a more specific and useful survivability chart.

Topology

Data must be specific for the type of topology, otherwise information can lead a search planner to give up too early, not search a large enough area, or to look in the wrong place. Three major types of topology exist in Virginia. They include a flat tidewater, the rolling hills of the Piedmont, and the Appalachian Mountains. Preliminary analysis and discussions indicate differences will appear among critical wanderers. Personal discussions with search and rescue team leaders from the West indicate critical wanderers travel further than the 0.5 mile median found in Virginia.[41] Important topological differences have already been documented for hikers, elderly, children, and hunters.[18,19] Since no other studies on critical wanderers have been conducted it is impossible to analyze any other topology differences at this time.

Urban versus Rural Searches for Wanderers

Search and Rescue resources in Virginia have only recently started being called into cities or urban environments to conduct searches for critical wanderers. It is expected that several

differences in the subject profile may be found. Due to the higher density of people it is expected that a larger number of finds can be attributed to non-searchers, road patrols, and media involvement. Due to a vast network of roads and public transportation, the distances these subjects travel should be greater. Coupled with potentially shorter times to locate subjects and the availability of shelter the survivability rates should be higher. No studies have specifically addressed these concerns. Preliminary results of the investigator included only 11 urban searches and 31 rural searches.[20] It may be necessary to make different recommendations if they are located in an urban or rural location.

Wandering from Nursing Homes versus Residence Similar analysis between those who wander away from their residence versus a nursing home may also elicit important differences. Those patients in a nursing home may have a more severe dementia that those still in a private residence. The wandering behavior in a nursing home may be directed towards returning home or even escapist while the wandering seen from a residence may be caused by disorientation or seeking a favorite place. No studies have directly assessed this issue. Preliminary results of the investigator (n=42) showed no difference in age, sex, race, distance found from the point last seen, and time required to locate subject between the two groups.[20] In any case, recommendations for initial actions for a primary Caregiver in a home setting and those responsible in an institution will be different.

Wandering Sociedemographics Age, sex, and race are demographic characteristics that a search planner may easily obtain and which may help predict the subject's behavior. It is conceivable that the older the search subject, the higher the chance of mortality and the smaller the distance they might travel. Alternatively, it has been shown that age has no relationship with cogitative or behavioral disturbance or the rate of progression of AD.[45]

In fact, AD sufferers may be healthier than other age controlled elderly [46] and by definition only suffer initially from a loss in cognitive domains.[1] Synder *et al* showed wanderers do not differ from non-wanderers on the basis of age, sex, or martial status.[2] Koester and Stooksbury also found no difference in survivability or distance traveled due to age or sex.[20]

Directionality

No current studies have addressed the issue of directionality among lost subjects. Directionality is the examination of a lost subjects tendency to travel in specific compass directions. Directionality is an innate behaviour among migrating animals and the possibility exists it may occur in those suffering from dementia. A search and rescue incident commander has suggested the possibility of an East-West trend related to the phenomena of sundowning, common among AD wanders.[2]

Materials and Methods

Database Source:
In 1986, The Virginia Department of Emergency Services (VDES) introduced a new management system that used selected operations personnel to handle all request for SAR assistance. The new management system initiated a record-keeping and database system. This study looked at data from June 1986 with the first state recorded mission to December 1996. This includes over 550 cases. Only searches issued a DES incident or mission number will be included in analysis. The database is used for both the retrospective and prospective studies.

The principle investigator collected from VDES copies of Missing Person Reports, After Action Reports, and Virginia SAR Council Mission Summaries. The principle investigator followed up with Virginia Search organizations for any missing data. Search and Rescue organizations keep all original search related materials on permanent file for training and legal purposes. The point last seen (PLS) and the find location of the subject was plotted

on 7.5 minute United States Geological Survey topographic maps. The distance from the PLS will be calculated as a straight line connecting the two points regardless of any actual path taken. The topology will be classified as either mountainous, Piedmont (rolling hills), or flat (tidewater). Using U.S. Census maps and definitions the area will be classified as wilderness, rural, suburban, or urban.

Prospective Study Methods
Once contacted by a local law enforcement official, VDES coordinates the response of state search and rescue resources (search managers, blood hounds, air-scent dogs, horses, helicopters, mantrackers, and ground searchers). The principle investigator as a part time employee of VDES was notified of all possible AD related searches that occurred from June 1996- December 1997. The principle investigator responded to possible AD searches to collect information from caregivers and in some cases to function as the Incident Commander. Incidents were classified as a possible AD, AD related disorders, healthy elderly, or excluded from the study.

Criteria for Inclusion:
        The criteria for inclusion as a possible AD: 1) Subject is a critical wanderer (subject location unknown and disappeared of their own free-will). 2) Age on onset between 40 and 90. Greater weight given to those older than 65. 3) No history of alcoholism or mental retardation. 4) No history of psychosis prior to loss of cognitive ability. 5) Caregiver states subject experiencing memory impairment or behavioral disturbances for more than 6 months. 6) Positive history of decline in behavioral characteristics with DAD. 7) Positive deficits on DAD with a score at or below 30 OR 8) A previous diagnosis of possible or probable Alzheimer's, made by a physician or researcher.

        The criteria for inclusion as possible AD related disorders will involve the same criteria as 1-7. Criteria number eight will be

substituted with those diagnosed with Multi-Infarct, Parkingston's Dementia, Symptomatic Hydrocephalic, Korsakoff's Syndrome, Pick's Disease, Huntington's Disease, or Spongiform Encephalopathy by a physician or researcher.

        If the subject is excluded from the above categories they will be evaluated for the normal elderly category. Borderline cases of AD or AD related that were rejected for the aforementioned were not considered for healthy elderly. Lost normal elderly should show significant differences and will serve as a control group. The criteria is (1) age 60 or older, (2) no history indicating dementia of any form, (3) no history of psychosis, hallucinations, or mental retardation (3) no history of being despondent (suicidal), (4) no searches caused by murders, kidnaping, or other related crimes, (4) no searches caused by water related accidents (boating, crossing stream, etc). If the subject does not met the normal elderly category they will be excluded from the study. The determination will be made by the principle investigator.

Data Coding:
The data questionnaire was completed by the principle investigator during or at the conclusion of the search. The principle investigator questioned the caregiver. The test was given during the search incident. In incidents that were concluded before the arrival of the Principle Investigator, data was collected within one week. Data forms were reviewed for simplicity by the twenty-six search and rescue organizations and law enforcement agencies belonging to the Virginia Search and Rescue Council.

   The data questionnaire collects information on the location of the search, location last seen, activity when last seen, time and date when last seen, time caregiver noticed subject missing, time local law enforcement notified, initial efforts of the caregiver, initial efforts of law enforcement, time search and rescue teams notified, time search and rescue teams deployed

into field, time and date subject located, topology of area, verifiable clues found during search, subject distance from the point last seen, subject responsiveness, search techniques used during the search, search technique used to locate subject, specific type of terrain subject located in, change in elevation of subject, subject's activity at time of find, distance from nearest trail or road, medical condition when found, and length of evacuation to road head (time and distance). Search teams were also be requested to supply a copy of the topographical map displaying point last seen, location of verifiable clues, clues giving a direction of travel, location subject found, and the location(s) the subject was found on any previous caregiver conducted searches.

Basic epidemiological information was also collected. Information will include sex, race, age, marital status, and living quarters, A series of questions relating to past life experiences, physical activity, current and past personality traits, and possible target locations will be included.

In order to determine the severity of AD in a missing subject requires the evaluation of existing tests and administration of a test to the caregiver. Cognitive ability will be estimated by the informant-derived Blessed dementia scale,[47] disability assessment for dementia (DAD), and Progressive Deterioration Scale (PDS/CGIC) which are similar to an ADL scale,[48,49] and an IADL.[25]

After a search with a successful outcome (survival of subject) the principle investigator will follow-up after the patient has stabilized from any disorders due to the search (dehydration, hypothermia, etc.). The follow-up will include the MMSE a standard cognitive tests to precisely measure the severity of the disease.

Retrospective Study
The same eight step criteria used in the prospective study for classification as a possible AD, AD related disorder, or normal elderly

subject was used with two modifications. Due to the retrospective nature of the data it was impossible to obtain a DAD or PDS score. The lost person questionnaire contains medical information that allows validations of a possible AD or related AD diagnosis.

The previous maps plotting the subjects start and end points will be used. In addition the clue map and log will be used to determine those searches where a direction of travel was obtained. In those searches with a direction of travel the find location can be expressed as a vector off of the predicted location.

Statistical Analysis
The study collects a wide array of information from caregivers and searchers. In order to determine which information is useful in predicting the subject's location and survivability, statistics will be used. Data will be entered into MS Excel 5.0, a spreadsheet computer program. Several statistical tests to analyze the continuous and qualitative variable will be used. The statistical packages, SPSS and Statistica will analyze this data. Descriptive statistics will describe the mean, median, and variance. Traditional ANOVA will test for significant differences between categorical variables (independent) on continuous response variables (dependent)(e.g., race versus distance found from place last seen).[50] Linear regression will analyze the continuous variables. The regression equations will be evaluated for use as a predictive tool (e.g., distance found from the place last seen as a function of age).[51] Discriminant factor analysis will allow (using the behavioral tests) the development of a set of predictive equations for lost subject survivability.[52] Contingency tables and chi square test will test the relationship between qualitative values. This will also allow testing for race or sex differences in lost person behavior and survivability.[53] Analysis of the factor loadings from factor analysis will allow the behavioral test to be a predictive instrument. Regression of the factor scores on

the continuous variables will produce predictive instruments.[52] Significant relationships between a predicted direction of travel and the actual direction is determined by the modified Raleigh test.[51] Whether there is a significant difference between two groups (survivors versus non-survivors) can be tested by the Mardia, Watson, and Wheeler test.[54]

Results

Eighty-seven (15%) of 565 recorded state incidents involved possible ADRD sufferers (**Figure 1**). One search involved two ADRD patients that remained together. This particular category was the second largest in the data set. In all but one search, the search effort or others located the patient. The other most prevalent search types included children (18%), suicidal (14%), drowning (11%),
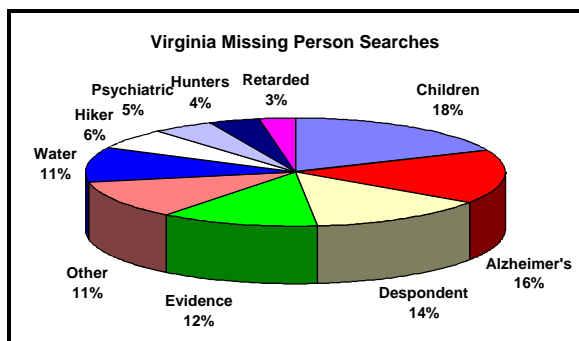
Figure 1

murders (12%), and hikers (5%). The drowning and murder cases usually reflect requests for dog teams only. The ADRD searches occurred over a ten year period.

Patients fall into three classes based on their medical condition at the time of the find. Team leaders with at least basic first-aid training make the field classifications of uninjured, injured, or deceased.

The medical condition of the ADRD patients after being found varied greatly.

Forty-two patients (51%) could be escorted back to their residence and required no medical attention. Twenty-three patients (28%) required an evacuation team. The state forms do not always specify the specific medical problem and any field diagnosis was not verified by hospital records. Experienced EMTs with supplemental training in wilderness disorders made the field diagnosis. ADRD patients requiring an evacuation suffered from hypothermia (67%) and/or dehydration (33%). In two cases, patients were field diagnosed as suffering from both disorders. All evacuated patients survived and were discharged from the hospital. Eighteen patients (21%) were found deceased and appeared to have succumbed to hypothermia (n= 10), dehydration (n= 3), or drowned (n= 2). For one patient, the cause of death was neither determined nor recorded. No evacuated or deceased patients demonstrated any trauma based upon field evaluation.

In searches for normal elderly subjects (n= 33), thirteen subjects were found uninjured (48%); four subjects required evacuation (15%) due to hypothermia and dehydration; and ten subjects (37%) were deceased (heart attack, drowning, hypothermia, and unrecorded).

There is no relationship between the age of the ADRD patient and outcome of the patient. There is also no relationship between the age of elderly patients and the outcome of the subject. Fifty-nine (59) of the ADRD searches and twenty (20) elderly searches had the patient's distance from the Point Last Seen (PLS) recorded. The missing data points represent a failure to complete the data form correctly. The mean distance the DAT patient was found from the PLS is 0.9 km (0.6 miles). The median distance is 0.8 km (0.5 miles) with a range of 0-3.2 km (0-2 miles). For elderly cases without ADRD the mean distance found from the PLS is 2.6 km (1.6 miles). The median distance is 0.8 km (0.5

Statistic	Alzheimer's	Elderly
n	87	33
Mean	0.6 miles**	1.8 miles
s	0.5 miles	0.5 miles
Median	0.5 miles	0.5 miles
x Age	76	70
s	9.2	8.3
Males	67%**	67%**
Females	33%**	33%**
Uninjuried	51%	48%
Injuried	27%	15%
Deceased	22%	37%
50% Zone	0.3-0.6 miles	0-0.5 miles
75% Zone	0.7 miles	2.5 miles
Max Zone	1.5 miles 94%	4.8 miles 95%

Table 1

	<12 h	>12 h	> 24 h
Walk-out	40	19	7
	93%	48%	32%
Evacuated	3	13	8
	7%	33%	36%
DOA	0	8	7
	0%	20%	32%

Table 3

Subject uninjured	12.3

Table 2

miles) with a range of 0-8.0 km (0-5.0 miles) (**Table 1**). There is no relationship between the DAT patient's age and distance from the PLS.

Survivability

There was a significant increase in morbidity and mortality as the total time elapsed to find the patient increased. There was also a significant increase in morbidity and mortality

as the time increased from when trained SAR resources were notified and the patient was located (**Table 2**). The two uninjured ADRD patients located after a considerable delay were in an uninhabited former residence. Among those patients located within 12 hours of being last seen, no deaths occurred (**Table 3**). In six cases the search was suspended without the patient being found. These searches are not included in the time to find analysis though in five cases the body was eventually located within the search area.

Total Time to Locate Subject	Hours
Subject DOA	83
Subject uninjured	36
Mean SAR contact time	**Hours**
Subject DOA	50.0

Local Terrain
Most ADRD patients are last seen at either their own residence or a nursing home (Table 4). In addition, all twelve patients spotted on a road initially departed from a nursing home or residence.   The local terrain in which the patient was located was recorded in fifty-six cases (**Table 5**). The majority of patients are in drainages/creeks or heavy brush/briars. In the ten cases in which patients were in a house, half

were hiding in their own house and half traveled to a previous residence.   In most searches the patient is not found by search teams but found wandering by others. This includes searches where the state issued a mission number but the patient was found before the arrival of search and rescue resources. Sweep, scratch (hasty) teams, and helicopters are the most successful organized technique used to find ADRD patients (**Table 6**).

Topology

The topology could be classified for Forty-six searches. Searches were classified as Mountainous (n=7), Piedmont (n=24), or Mountainous (n=15). Preliminary classification was based upon the geographic location. Those searches occurring in counties that contain mountains were further examined to determine if the actual search area occurred in rolling hills (Piedmont) or in a mountainous area. ANOVA showed no significant difference between the means of the distance from the point last seen (p=0.32). The median for the tidewater area was 0.3 miles and 0.5 for both the Piedmont and mountain topology.

Place Last Seen		
Personal Home	26	37%
Nursing Home	22	31%
Roadway	12	17%
Vehicle	3	4%
Day-Care	2	3%
Camping	2	3%
Field	1	1%

Table 4

Environment of Find		
Bushes/Briars	16	29%
Creeks/Drainages	10	18%
Open Field	10	18%
House	10	18%
Road	4	7%
Woods	4	7%
Swamp	2	4%

Table 5

Find Techniques		

Non-searchers	22	35%
Scratch (Hasty)	10	16%
Sweep	9	15%
Helicopter	9	15%
Air-Scent dog	6	10%
Road Patrol	3	5%
Other	3	5%

Table 6

Time of day: The times at which patients were last seen by caregivers or a member of the general public are distributed equally over the daylight hours. No critical wanderers departed between 0001 and 0530. This indicates a cluster during the hours of 0700 and 2400. The Rayleigh test for significant clustering indicates this clustering is significant (r=0.45, p <0.001) compared to random clustering with a vector at 1500 (225°)[54].

Time of year: **Figure 3** depicts the occurrence of critical wanderer searches in Virginia by
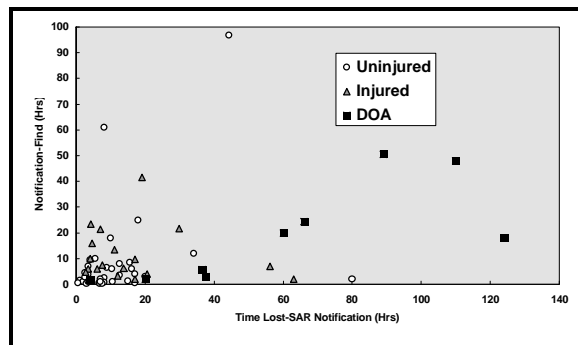
Figure 2

month. The warm season or frost-free period for Virginia starts in April and runs to October[55]. Fifty-nine (69%) of the searches occurred during the frost-free period. While 31% of the searches occurred during the five cold months, accounting for 47% of the fatalities. The difference in case distribution of cold versus warmer months just missed standard statistical significance (χ^2=3.73, p<0.053). The cold versus warm distribution

of fatalites also just missed standard statistical significance ($\chi^2 = 2.57$, $p < 0.10$).

Location: In 26 cases (54%), the patient lived in their own residence or with family in a residential setting. In 32 cases (46%) the patient lived in a nursing care facility. Only one search occurred at a Alzheimer's special care unit. That subject was located within the facility in another residents bed. Using discriminant analysis there was no significant differences in age ($p=0.65$), time required to find ($p=0.68$), time elapsed till SAR resources were contacted ($p=0.30$), or distance from the point last seen ($p=0.64$) between those living in a care facility or in the community.

Fifty-one (67%) of the searches were rural, sixteen urban (21%), and nine suburban (12%)[56]. ANOVA indicates no differences between the three settings when analyzing age ($p=0.40$), time required to find ($p=0.83$), time elapsed until resources called ($p=0.70$), or the distance from the point last seen ($p=0.87$). The most notable differences occurred among the percentages of subjects found by searchers, thru investigative efforts, or suspended searches. The greatest difference is between rural and urban searches for percentage of investigative finds. This difference just misses standard statistical significance ($\chi^2 = 5.51$, $p < 0.06$).

Population Density Outcomes			
	Rural	Suburban	Urban
Subject Found	45 88%	7 78%	10 63%
Investigative Find	2 4%	1 11%	4 25%
Search Suspended	4 8%	1 11%	2 12%

Table 7

Resource Requests: **Figure 2** depicts the relationship between the time elapsed until state SAR resources were contacted and the time state SAR resources required to locate the patient. The abscissa includes the time required to contact state SAR resources. The contact time includes the time for someone to realize the patient is missing, contact local law enforcement, and finally the time local law enforcement officials take to request state resources. The ordinate includes the time required for the state SAR resources to locate the patient. The locate time includes the time required for SAR resources to mobilize, travel to the search, collect initial information, and find the patient. The data does not include six searches which were suspended without the patient being found. We did not include these searches even though the body was located eventually within the search area. The sooner SAR resources respond, the sooner the patient is located is indicated by the tight cluster (**Figure 2**). There was only one death when the patient was found within 24 hours. The average time to contact SAR resources was (83.6 hours $\sigma=39.0$) for searches that resulted
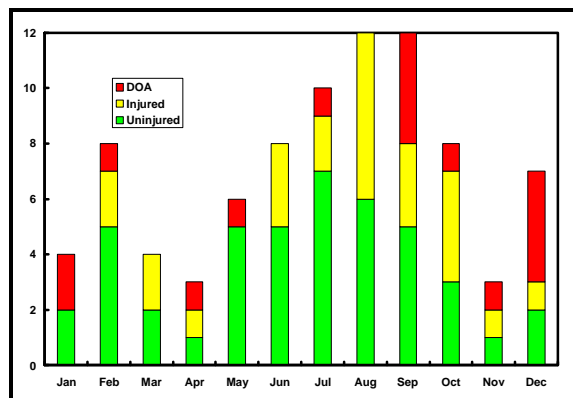
Figure 3

in a fatality. The average time to contact SAR resources was 10.3 hours ($\sigma=9.8$) for searches that resulted in the patient being uninjured. The delays in contacting SAR resources were due to caregivers not noticing the missing patient, failure to contact local law enforcement, or the failure of local law enforcement to request state SAR resources in a timely fashion.

Sex: Fifty-eight (67%) of the searches were for males and 28 were for females (33%). Using estimates of the prevalence of Alzheimer's Disease among each of the three age brackets[57] and the 1990 Census for

Virginia[56] expected values are 25,939 males (33.4%) and 51,749 females (66.6%) in Virginia. Chi-squared analysis indicates that this falls outside the expected distribution ($\chi^2 = 44.8$, $p<0.001$). There are no other significant differences between sexes for age, time required to find, time elapsed until resources called, or distance traveled from the point last seen.

Race: The race of the patient was recorded in 71 searches. Twenty-four patients (34%) were African-American and 47 (66%) were white. Using Evans *et al* [56] estimates of the prevalence of Alzheimer's Diseases and the 1990 Census, it is expected that 12,377 (15.9%) African Americans and 65,311 (84.1%) whites in Virginia are afflicted. The observed racial distribution is outside our expected distribution ($\chi^2 = 17.0$, $p<0.001$). There is also a significantly greater ($\chi^2 = 82.5$, $p<0.001$) number of African Americans patients found

| Race Differences		
Status	Negro	Caucasian
Uninjured	8 (40%)	23 (53%)
Injured	4 (20%)	12 (28%)
DOA	8 (40%)	8 (19%)
Notification Time	29.5 hours	19.1 hours

Table 8
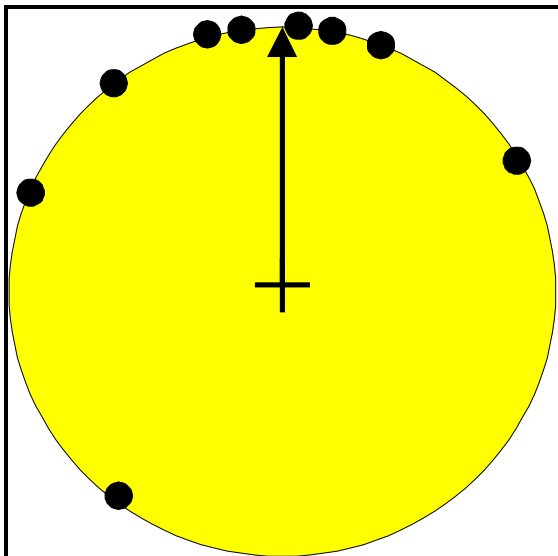
Figure 4

deceased than whites patients during searches (**Table 8**). Discriminant analysis indicated a difference ($p<0.01$) in the time required to locate African American patients over white patients. The difference was due to the longer time ($p<0.001$) from the time last seen to the activation of search resources. There was no difference in the time required to locate African American patients once SAR resources are activated.

Direction of Travel

Documentation of a direction of travel only occurred for nine searches. The direction of travel was usually established by a combination of the Initial Planning Point (IPP) and a verifiable clue. Bloodhound trails were not considered a verifiable clue. Once a direction a direction of travel was obtained it was normalized to represent a vector of 0 degrees. The location of the subject is expressed as an angle off the direction of travel. Five of the nine finds (56%) occurred within 30° degrees of the direction of travel. The Rayleigh test for significant clustering indicates this in non-random ($p<0.001$). In the one case where the subject was located in nearly the opposite direction of the predicted direction of travel, the subject was located 83 yards (75m) from the clue and 33 yards (30m) from the IPP.

Distance off Travel-Aid: A travel-aid was defined as a road, trail, or other feature that would aid travel. The find location was recorded in 56 searches. Fourteen of these searches (25%) resulted with a find along a travel-aid. The distance from a travel aid was recorded in 23 searches. The distance was calculated my measuring the shortest distance from a travel aid to the find location. The descriptive statistics are reported in **table 9**.

	Distance (Yards)	Distance (M)
Median	33	30
Mean (x)	100	91
(s)	138	126
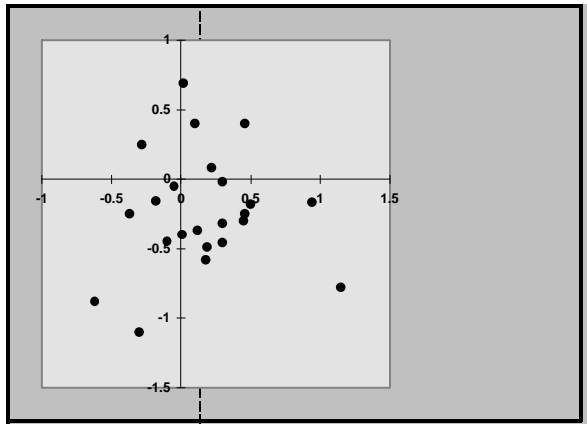
Figure 5

| Range	1-500	1-457
n	23	23

Table 9 Distance from Travel Aid

Directionally Twenty-three cases had sufficient documentation to plot the compass vector and distance the subject was found relative to the IPP. The plots of the find location are shown in **figure 5**. Five subjects (22%) were found north of the IPP, while eighteen (78%) of the subjects were found south of the IPP. This distribution is outside expected distributions (χ^2 = 8.2, p<0.01). No East-West difference was seen (χ^2 =1.4, p=0.24). A closer examination of the South-East and the South-West quadrants found that 75% of the subjects found in each quadrant was last seen in the afternoon.

Previous wandering: Information on previous wandering was collected solely from the prospective phase of the study. The principle investigator was able to collect data on eight searches during the one-year study period. Information on previous wandering incidents were collected on six of these incidents. Five of the six (83%) had a previous history of wandering with an average of 2.8 incidents and a range of 1-5. The distance from the point last seen varied greatly from the data previously collected. The distance of previous incidents

ranged from 0-12 miles with an average of 2.5 miles and a median of 0.2 miles.

Severity: The severity of ADRD was measured using three different tests. During the search the DAD and the Subjective Severity Index (SSI) was administered to the caregiver. After a successful search (subject found alive) the principle investigator also administered the
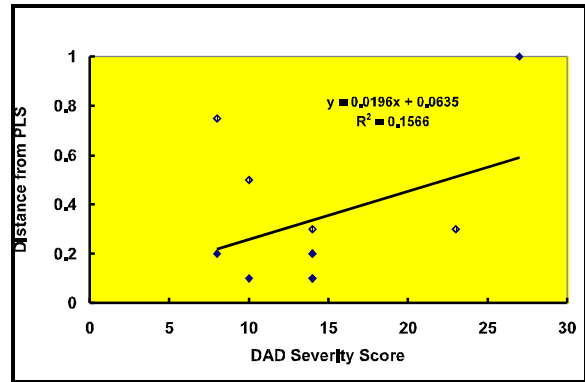
Figure 6

MMSE to the search subject. With the limited number of fully documented cases (n=6) all results are preliminary. DAD scores ranged from 8-33. The SSI classified three subjects as mild, one with moderate, and two with severe dementia. The SSI classifications agreed with DAD and MMSE scores. Further data is required for meaningful statistical analysis. The average distance from the IPP for mild ADRD (n=4) was 3.4 miles, moderate (n=4) 3.15 miles, and severe cases (n=7) 0.28 miles. The additional cases were obtained from multiple incidents from some of the search subjects. An ANOVA found no statistical difference (p=0.27) between the three groups. A regression line (Figure 6) between the DAD severity score and the distance from the IPP also found no significant correlation (p=0.5, R^2 =0.13).

Discussion

During the retrospective component of the study, the caregivers along with medical

records provided the data characterizing missing persons as suffering from ADRD. Investigators within Virginia are suspicious of the potential of ADRD in all elderly subjects. The Lost Person Questionnaire, a standard data collection tool used on all state searches, prompts the investigator to pursue mental alterations. There was no follow-up behavioral testing due to both the circumstances of a search and the retrospective nature of this phase of the study. The distribution of search incidents for the different patient profiles reflects two major study factors. In Virginia state mission numbers are only given after local law enforcement efforts have failed to locate the subject. In addition, the terrain and number of trails and roads make it difficult to become truly lost in the state. In fact, the profiles of ADRD, mentally retarded, despondent, psychotic, and child all represent decreased spatial and/or cognitive abilities and together account for 56% of the state case load. Using current estimates of the prevalence of AD[58] and the 1990 population of elderly within Virginia[56], an estimated 68,500 Virginians suffer from ADRD. This represents 1% of the population compared to the 16% of all searches for ADRD patients. The data allows the development of a preliminary ADRD patient profile. Patients usually disappear from their private residence or a nursing home. More recently, an increasing number of cases are occurring from day-care centers. Once the patients become lost they are generally found close to the PLS. This data supports the few anecdotal case studies reported in the literature[4,13]. In addition, it supports the personal experience of the author reported elsewhere[20]. This finding is somewhat surprising considering DAT sufferers may be healthier than other age controlled elderly[59] and by definition only suffer initially from a loss in cognitive domains[1]. A possible explanation is that moderate DAT patients who showed shorter step length, lower gait speed, lower stepping frequency, greater step-to-step variability, and greater sway path[60]. While the investigators have heard many reports of Alzheimer's patients walking great distances (10-15 miles), no such case appeared in the Virginia retrospective case load. It is possible that as a larger data pool develops the mean distance of 0.9 km will increase. The median distance of 0.8 km will most likely remain stable. During three different studies by the author (n=24, n=42, n=87) both the median and mean have remained the same with additional data points. However, the prospective study, which included searches not involving law enforcement or state resources did include several statistical outliers that traveled 12, 8, and 4 miles. It is unknown if patients spend considerable time wandering or if they walk a fairly direct path. The considerable number (18%) of DAT patients found in drainages or creeks supports the following a path of least resistance hypothesis. This indicates they walked downhill. Another 29% of the patients appear to have become stuck in thick brush or briars (a feature untrained searchers often avoid). Together (47%), both terrain features indicate a scenario of the patient traveling a path of least resistance till they reach a creek or get stuck in briars.

The age of the patient has no predictive value in the patients' outcome (class) or distance from the PLS. This corresponds well to studies that show that age has no relationship with cognitive or behavioral disturbance or the rate of progression of ADRD[45]. The relationship between patients' outcome and the time elapsed to locate does have clear implications. Family members must not hesitate to contact law enforcement officers when a ADRD patient becomes missing. In turn, once law enforcement officials have determined the need for a search effort they must not hesitate to activate specialized SAR resources. These resources include management teams, trackers, tracking dogs, air-scent dogs, helicopters, and clue aware scratch (hasty) teams. The twenty-four hours for optimal results requires an immediate and aggressive response from all parties concerned.

Unfortunately, the state forms do not

consistently provide information about the exact medical condition of the patient when found. If the patient was deceased, the Incident Commander did not receive a copy of the autopsy or the autopsy did not specify the exact cause of death. In those patients requiring evacuation, making a field diagnosis is often difficult. However, none of the data forms report trauma. This is rather surprising considering the large number of DAT patients (29-36%) that experience serious falls[5,36]. In fact, falls are more likely to occur in ADRD patients than in elderly controls[61]. The lack of any falls may be due to either the small database, lack of any autopsy results, or perhaps the difficulty in detecting evidence of a fall in a hypothermic patient. The only recorded disorders included hypothermia, dehydration, drowning, and unknown. Therefore, it appears ADRD patients are most likely to succumb to the environment and not to any injuries or pre-existing diseases.

The data suggests critical wanderers are last seen between 06:00 and 24:00. There was no particular tight cluster of time, supporting Martine-Saltzman *et al*.findings and suggesting the critical wanders in this study suffer from severe dementia[62]. Although no case was reported between 00:01 and 06:00 this does not preclude nocturnal wandering. Several cases of critical wandering were initiated after sunset. Furthermore, in one case while the patient was last seen at 22:30 the caregiver also reported hearing the patient leave the house at 02:30. The small sample size may have resulted in the lack of critical wanders between 0001 and 0600. Finally, care givers or institutional staff may not be present or awake to see the patient depart during these times.

The greatest number of searches occurred during the warm season. We defined the warm season as the frost free period and the cool season is the period in which freezing temperatures are likely to occur. The number of searches generally increased during the warm season and decreased during the cool season. We observed a slight increase in searches during February. Due to the small sample size no conclusions are drawn. Virginia's February often experience warm spells after protracted periods of cold. This increased wandering in February agrees with the undocumented observation of an increase in wandering after a cold period[2].

There are no significant differences between searches in urban and rural locations. This may be due to the small sample size. Alternately, Virginia SAR resources only respond into urban locations when significant parks or wooded areas exist. A larger percentage of searches with investigative finds in urban areas is not surprising. Subjects had ready access to public transportation and more opportunities to wander into public buildings or private residences.

This study indicates the need for an immediate and aggressive response to a critical wanderer. A critical window of 24 hours becomes apparent for survival. While there was only one fatalities when the patient was located within this time frame, 30% of those found still required assisted evacuation. It is possible that any delay in initiating the search may have resulted in even more fatalities. In order to locate patients within the 24 hour window, an early activation of SAR resources is required. There was a positive relationship between the longer the time to activate SAR resources the longer it takes SAR resources to locate the patient. This may be due to a larger search area, decay of clues such as footprints and scent trails, or a greater chance of an unresponsive patient. More important was the relationship between the longer it takes to find the patient and the greater chance of mortality. This relationship has two confounding explanations. Unresponsive deceased patients are often more difficult to find. In addition, the longer the patient is exposed to the elements, the greater is the risk of mortality.

The lack of any statistical difference among the three types of topology was not predicted. This might have resulted from the small distances ADRD patients travel. A small

insignificant difference was seen in the flat tidewater area with the subjects showing a mean of 0.2 miles less than Piedmont or Mountain areas. This would agree with the pattern seen among children and hikers in flat versus vertical topology. Another explanation may be that vegetation and barriers are more important in predicting travel than actual topology.

To better predict DAT missing patient behavior requires a much larger data pool. As Alzheimer's continues to increase in prevalence it unfortunately will become easier to collect data. We expect that the distances traveled by ADRD patients will be greater in less densely vegetative regions. Numerous roads and paths criss-cross even the most wilderness regions in the East thus limiting the distance that one can travel without crossing a road. An obvious need to expand the database on a national basis in various types of terrain under must be pursued.

Summary

These preliminary findings indicate Dementia of Alzheimer's Type patients generally:
! Leave their own residence or nursing home and start traveling along roads.
! The patient is usually located (89% of all cases) within one mile (1.2 km) of the Point Last Seen.
! If the patients were not on the road itself (14%), they are usually in a creek/drainage (28%), and/or caught in briars/bushes (33%).
! Subject usually found a short distance from a road. Median 33 yards.
! The majority of patients succumb to the environment (hypothermia, dehydration) and require evacuation (35%) or are deceased (19%).
! Subject will not cry out for help or respond to shouts.
! Subject will not leave many physical clues.
! Subject may attempt to travel to a former residence or to a favorite location.
! Subject has previous history of wandering.
! Coexisting medical problems that limit mobility are common.

Suggested Search Techniques:
! Early use of trackers at point last seen (PLS)
! Early use of tracking dogs at PLS and along roadways.
! Early deployment of air scent dog teams into drainages and streams, start near PLS.
! Throughly search the residence/nursing home and surrounding grounds and buildings; repeat every few hours.
! Cut for signs along roadways and trails.
! Search heavy briars/bushes; remind field team leaders of this.
! Dog teams and ground sweep teams (in separate sectors) expanding from PLS.
! Air scent dog teams and ground sweep team tasks 100 yards (initially) parallel to roadways.
! Search nearby previous homesites and the region between homesites and PLS.

Acknowledgments

References

1 McKhann G., Drachman, D., Folstein, M., Katzman, R., Price, D., Stadlan, E.M., Clinical diagnosis of Alzheimer's Disease: report of the NINCDS-ADRDA Work Group under the auspices of Department of Health and Human Services Task Force of Alzheimer's Disease. *Neurology* 1984;**34**;939-44.

2. Snyder, L., Rupprecht, P., Pyrek, J., Bredhus, S., Moss, T. (1978) Wandering *The Gerontologist* 18:3,272-280.

3. Butler, B., B. Barnett (1991) Window of wandering. *Geriatric Nursing* September/October 226.

4. Burnside, I. (1980) Wandering behavior. in Burnside, I., ed. *Psychosocial nursing care of the aged, Second edition.* New York, NY.: McGraw-Hill, 298

5. Teri, L., Larson, E., Reifler, B. (1988) Behavioral disturbance in dementia of the Alzheimer's type. *J. Amer. Geriatrics Soc.* **36**(1):1-6

6. Teri, L., Hughes, J., Larson, E. (1990) Cognitive deterioration in Alzheimer's disease: behavioral and health factors. *J. of Gerontology* 45;2:P58-63

7. Iigima, S. (1991) Prevention and treatment of dementia: what should we do today? *Japanese Journal of Geriatrics.* 28(1):165-9

8. Deutsch, L., Rovner, B. (1991) Agitation and other noncognitive abnormalities in Alzheimer's disease. *Psch. Clin. of N. Amer.* 11;2;311-51.

9. Coons, D. (1988) Wandering *The Am. J. of Alzheimer's care and Related Disorders and Research.* Jan/Feb 31-36

10. Coons, D. Residential care: A link in the continuum of care. In Mace, N. (ed) *Dementia care: Patient, family, and community.* Baltimore, the John Hopkins University

11. Bartol, M. (1983) Reaching the Patient. *Geriatric Nursing* July/August;234-36.

12. "Deadly Mix: Dementia and Wandering" Symposium. Gerontology Society of America. 1996 Washington. D.C.

13. Hindlian, N. (1988) Case histories of wandering. *The Amer. J. of Alzheimer's Care and Related Disorders & Research.* Jan/Feb p.38-9.

14. Hill, K. (1991) Predicting the behavior of lost persons. *NASAR Conference Proceedings.* NASAR, Fairfax, VA.

15. Hill, K. (1996) Distances Traveled and Probability Zones for Lost Persons in Nova Scotia. Unpublished in Managing the Lost Person Incident.

16. Silverstien, N., Salmons, T., (1996) Wandering Behavior in community-Residing Persons with Alzheimer's Disease Registered in safe Return. *Gerontology Institute* Boston. MA

17. Koester, R., Stooksbury, D. (1992) Lost subject profile of Alzheimer's. *Journal of Search, Rescue, and Emergency Response...Response.* 11:**4**;20-26.

18. LaValla, R., Stoffel, R., Jones A. (1997) *Managing Search Operations* 4th Edition. Emergency Response Institute, Olympia. Washington.

19. Hill, K. (1997) *Managing the Lost Person Incident.* National Association for Search and Rescue. Chantilly, VA.

20. Koester, R., Stooksbury, D. (1995) Behavioral profile of possible Alzheimer's disease subjects in search and rescue incidents in Virginia. *Wilderness and Environmental Medicine,* 6,34-43

21 CDC Editorial note: Mortality Patterns-United States-1987 *MMWR* 1990;39:12193-6.

22. Rocca. W.A, Bonairto, S., Lippi, A., et al. Prevalence of clinically diagnosed Alzheimer's Disease and other dementing disorders: a door-to-door survey in Appignano, Macerata Province, Italy. *Neurology* 1990;10:623-31.

23. Durtigues, J., gagnon, M., Michel, P., et al. The Paquid research program on the epidemiology of dementia. Methods and initial results. *Revue Neurologique* 1991:117(3)225-30.

24. Morris, J., Heyman, A., Mohs, R., et al. (1989) The Consortium to establish a registry for Alzheimer's disease (CERAD) Part I. Clinical and neuropsychological assessment of Alzheimer's disease. *Neurology* 39;1159-65.

25. Galasko, D., Corey-Bloom, J., Thal, L. (1991) Monitoring progression in Alzheimer's disease. *J. Am. Geriatr. Soc.* 39:932-941.

26. Butler, R., Finkel, S., Lewis, M., Sherman, F., Sunderland, T. (1992) Aging and mental health, part 2: Diagnosis of dementia and depression. *Geriatrics* 47(June):49-57.

27. Stern, Y., Hesdorffer, D., Sano, M., et al. (1990) Measurement and prediction of functional capacity in Alzheimer's disease. *Neurology* 40:8-14.

28. Mirra, S., Heyman, A., McKeel, D., et al. (1991) The Consortium to establish a registry for Alzheimer's Disease (CERAD) Part II. Standardization of the neuropathologic assessment of Alzheimer's disease. *Neurology.* 41:479-486

29. Tomlinson B., Blessed, G., Roth, M., (1970) Observations on the brains of demented old people. *J. Neuro. Sci.* 11:205-242

30. Bull, M. (1978) Topographic distribution of neurofibrillary tangles and granulovacuolar degeneration in hippocampal cortex of aging and demented patients: a quantitative study. *Acta Neuropathol. (Berl)* 74:173-178

31. Amaral, D. (1987) Memory: Anatomical organization of Candidate brain regions. In F. Plum (ed): *Handbook of Physiology, Section1, The Nervous system, Vol. V, part 2.* Bethesda, MD:American Physiological Society, 211-294.

32. Rosene, D, Van Hoesen G. (1987) The Hippocampal formation o f the primate brain. In Jones, E., Peters, A (eds): Cerebral Cortex, Vol. 6. New York, Plenum, 345-455.

33. Van Hoesen, G. (1985) Neural systems of the nonhuman primate forebrain in monkey. *Ann. N.Y.Acad. Sci.* 444:97-112.

34. Hyman, B., Van Hoesen, G. (1989) Hippocampal and Entorrhinal cortex cellular pathology in Alzheimer's Disease. Chan-Palay, V., Köhler, C., Liss, A. (eds) In: The Hippocampus-New Vistas, New York 499-512.

35. Cooper, J., Mungas, D., Weiler, P. (1990) relation of cognitive status and abnormal behaviors in Alzheimer's disease. *J. of the Amer.*

Geriatrics Soc. 38;8;987-70.

36. Baumgarten, M., Becker, R., Gauthier, S., Validity and Reliabiliyt of the Dementia Behavior Disturbance Scale. *J. Am. Geriatrics Soc.* 38:221.

37. Yoshitake, T., Kiyohara, Y., Kato, I *et al.* (1995) Incidence and risk factors of vascular dementia and Alzheimer's disease in a defined elderly Japanese population: the Hisayama Study. Neurology 45(6):1161-8.

38. Snowden, D. *et al.* (1997) Brain Infarction and the Clinical Expression of Alzheimer Disease. *JAMA* 277(10)813-817.

39. Lavalle, P., Stoffel, R. (1987) Search is an Emergency: Field Coordinator's Handbook for Managing Search Operations. ERI. Olympia, Washington.

40. Robinson, A., Spencer, B., White., Kilbourn, A. (1988) Problems with wandering.

41. Personal communication with James Cooke, Sonoma County Sheriff's Department (CA). 1992

42. Personal Communication Dee Wild, La SAR-Dogs. 1992.

43. McQueeny j. Interview with Hebard C. In *Richmond Times-Dispatch.* May 13, 1996 E1

44. Barton, B. (1996) Searching for Lost Alzheimer's Subject. Http://home.ptd.net/~keystone/alzheim.htm

45. Ortof, E., Crystal, H. (1989) Rate of progression of Alzheimer's Disease. *J. Of Am. Geriatric Soc.* 37:511-14

46. Wolf-Klein, G., Silverstone, F., Brod, M. Et al. (1988) Are Alzheimer's patients healthier? *J. Of Am. Geriatric Soc.* 36:219-224.

47. Berg, L., Miller, J., Strorandt, M., et al. (1988) Mild senile dementia of the Alzheimer's type. 2. Longitudinal assessment. *Ann. Neurol.* 23;477-84.

48. Lawton, M., Brody, E. (1969) Assessment of older people: Self-maintaining and instrumental activities of daily living. *Gerontologist* 9:179-86

49. Katz, S., Downs, T., Cash, H., et al. (1970) Progress in the development of the index of ADL. *Gerontologist* 10:2030

50. Inversin, G., Norpoth, H. (1987) Analysis of Variance, 2nd ed. Sage University paper series on Quantitative Application in the Social Sciences, #1. Beverly Hills, Sage Publications.

51. Lewis-Beck, M. (1980) Applied Regression: An Introduction. Sage University Paper series on Quantitative Applications in the Social Sciences. #22. Beverly Hills, Sage Publications.

52. Tabachnick, B. Fidell, G. (1983) *Using Multivariate Statistics.* Harper and Row, Publishers, New York

53. McClave, J., Dietrich II, F (1982) *Statistics, 2nd ed.* Dellen Publishing Company, San Francisco

54. Batschelet, E. (1972) Recent statistical methods for orientation data. In *Animal Orientation and Navigation,* R. Galler, K. Schmidt-Koenig, G. Jacobs, and R. Bellevile, eds. pp.61-91, U.S. Government Printing Office, Washington, DC.

55. National Oceanic and Atmospheric Administration, (1985) *Climatography of the United States No. 20 (Virginia)* Asheville, N.C. National Climatic Data Center.

56. 1990 Census Summary Files-Virginia [Computer Laser Optical Disk STF1A] MS-DOS Version. U.S. Department of Commerce, Bureau of the Census, Data User Services Division, Vol. I. 1991

57. Evans, D.A., Scherr, P.A., Cook, N.R., *et al.* Estimated prevalence of Alzheimer's disease in the United States. *Milbank Mem. Fund. Q.* 1990;**68**:2267-89

58. Evans, D., Funkenstein, H.H., Albert, M.S. et al. (1989) Prevalence of Alzheimer's Disease in a community population of older persons. *JAMA* 262(18)2551-6.

59. Hindlian, N.S. (1988) Case histories of wandering. *The Am. J. Of Alz. Care and Related Disorders & Research.* Jan/Feb:38-39.

60. Visser, H., (1983) Gait and balance on senile dementia of Alzheimer's Type. *Age and Ageing.* 12:296-301

61. Morris, J.C., Rubin, E.H., Morris, E., Mandel, S., (1987) Senile Dementia of the Alzheimer's Type: An important risk factor for serious falls. *J. Of Gerontology.* 42(4)412-417.

62. Martine-Salzman, D., Blasch, B., Morris, R., McNeal, L. (1991) Travel Behavior of nursing home residents perceived as wanderers and non-wanderers. *The Gerontologist* 31:5,666-672.

Lost Person Behavior:

A Search and Rescue Guide on Where to Look – for Land, Air, and Water

Robert J. Koester
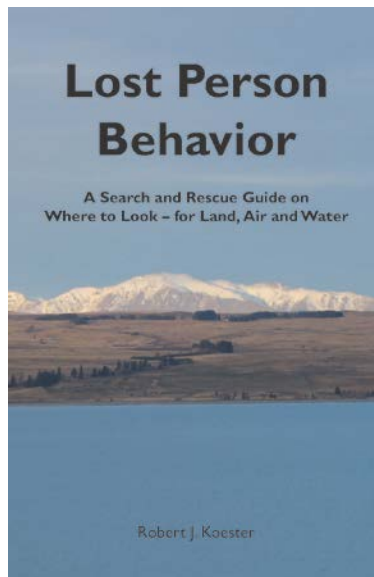
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Missing Aircraft Crash Site and Spatial Relationships to the Last Radar Fix

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Missing Aircraft Crash Sites and Spatial Relationships to the Last Radar Fix

Robert J. Koester; Ian Greatbatch

BACKGROUND: Few studies have examined the spatial characteristics of missing aircraft in actual distress. No previous studies have looked at the distance from the last radar plot to the crash site. The purpose of this study was to characterize this distance and then identify environmental and flight characteristics that might be used to predict the spatial relationship and, therefore, aid search and rescue planners.

METHODS: Detailed records were obtained from the U.S. Air Force Rescue Coordination Center for missing aircraft in distress from 2002 to 2008. The data was combined with information from the National Transportation Safety Board (NTSB) Accident Database. The spatial relationship between the last radar plot and crash site was then determined using GIS analysis.

RESULTS: A total of 260 missing aircraft incidents involving 509 people were examined, of which 216 (83%) contained radar information. Among the missing aircraft the mortality rate was 89%; most occurred in mountainous terrain (57%); Part 91 flight accounted for 95% of the incidents; and 50% of the aircraft were found within 0.8 nmi from the last radar plot. Flight characteristics, descent rate, icing conditions, and instrument flight rule vs. visual flight rule flight could be used to predict spatial characteristics.

CONCLUSIONS: In most circumstances, the last radar position is an excellent predictor of the crash site. However, 5% of aircraft are found further than 45.4 nmi. The flight and environmental conditions were identified and placed into an algorithm to aid search planners in determining how factors should be prioritized.

KEYWORDS: search & rescue, radar forensics, crash factors.

In 2013, within the continental United States, 63 missing aircraft incidents were reported to the Air Force Rescue Coordination Center (AFRCC). Search missions typically account for approximately 4% of the AFRCC missions.[3] However, they often account for a disproportionally larger amount of resources and cost. The challenge of finding a missing aircraft is immense, especially when a distress signal has not been received.

The 63 incidents resulting in searches is a much smaller subset of reported crashes. In 2013 the National Transportation Safety Board (NTSB) recorded 1431 aviation accidents with 339 fatalities.[17] Several papers have examined sport crashes,[8] helicopter crashes,[4,25] aeromedical crashes,[16] general aviation crashes,[18] instrument-rated private pilots,[21] and commercial aviation crashes.[19] In addition, the spatial distribution of crashes has also been examined.[10,13] Studies specific to missing aircraft include the New Two Area Method (given this name since it defines two different rectangles based upon the flight path with different probability densities)[20] and a similar study conducted in the United States.[7] Both of these studies looked at the spatial distribution of missing aircraft relative to the intended trackline to report track offset distances and percentage of route covered. These studies allowed the creation of probability of containment (probability of area) maps which have been incorporated into computer software that allows the optimal allocation of search and rescue resources.[1,2] However, the search areas created are quite large and only suitable for searches by aircraft or vessels. Limited work has also looked at the relationship between the crash site and where the aircraft first intersected with a weather front.[24]

The purpose of this work was to perform data acquisition and analysis that looks at retrospective search data for aircraft radar track, aircraft flight characteristics, and weather. One of the most powerful tools, when available, is radar track data collected by the Federal Aviation Administration (FAA) and/or military radar and forwarded to the AFRCC. This data, when properly understood and used by search planners, may generate more confined "areas of highest probability density" where missing aircraft may have crashed. The aircraft's radar track and last radar plot in particular provides the opportunity to update the last known position from the point of departure to the last radar plot. Determining the correct radar track and then the last radar plot is a component of radar forensics provided by the AFRCC, FAA, and 84th Radar Evaluation Squadron (84 RADES).[15] NASA developed a software tool known as World Wind Air Search and Rescue that displays previous radar tracks.[14]

In a search and rescue incident the most operationally critical information is making probabilistic projections of where the aircraft will travel beyond the last radar plot. Syrotuck was the first to describe Euclidian distances from the last known position to the eventual find location in ground search and rescue.[23]

In the extensive search for Air France flight AF477, no radar data was available.[5] However, this incident illustrates the value of search theory and the application of different models to establish a posterior probability distribution. The last known position of 2.98°N/30.59°W was provided by GPS in an Aircraft Communications Addressing and Reporting System. This message is sent every 10 min, which results in a 40 nmi search area.[5] A database of nine airline transport accidents involving loss of control while at cruise altitude was obtained by the Bureau d'Enquêtes et d'Analyses from the Russian Intrastate Airframe Group.[22] This data showed a median of 4.3 nmi and a maximum of 20 nmi (when adjusted to the 35,000-ft altitude to match AF477 altitude). An additional probability model was constructed by back drifting the floating debris from the wreckage. All three probability maps were combined and then adjusted for prior search efforts.[22] Using the new combined posterior distribution, the wreckage was found 6.5 nmi from the last known position in one of the highest probability areas.[5]

Ultimately, the goal of this research is to create spatial models that provide a probability of containment map that can be updated, in a Bayesian fashion, as new information is learned. Such a map will allow the use of formal search theory first described by Koopman for the nautical environment.[12] However, Stone has found it to be highly effective for many different search situations.[9] While Abi-Zeid and Frost[1] were the first to incorporate probability of area based upon route information into aircraft software, this study is the first to look at radar data as a key factor. The blending of radar track, mountainous versus flat terrain, intended route of flight, and observed weather in a computer generated visual presentation will aid search planners in identifying "areas of highest probability density." Search planners can then concentrate their efforts in those areas which will improve search efficiency, reduce search risk, and ultimately save search resources and more lives.

METHODS

Missing aircraft incidents within the continental United States that resulted in search efforts are recorded by the AFRCC. Data was collected for incidents covering a time period from 2002 to 2008. Data was collected during three trips to the AFRCC. The data was collected chiefly from the Honeywell SARMaster software (Ottawa, Canada) and associated file attachments. The file attachments (typically PowerPoint presentations showing the entire radar track and detailed information for the last part of the track) were collected under a nondisclosure agreement that limits their use and marks them as "For Official Use Only." Since the AFRCC area of responsibility is limited to the continental United States, the incidents are for the most part limited to the continental United States. The inclusion criteria from the AFRCC incidents included several factors. Only closed incidents were considered. However, some of these closed incidents represented previously suspended searches in which the aircraft was found after the formal search was concluded. Only those incidents that involved actual searches (versus rescues) for missing aircraft were selected. Only those incidents classified as distress were included. This precluded missions that were a result of a pilot failing to close out a flight plan or simply flying to another airport and failing to report. Finally, a find location for the aircraft must have been reported with coordinates.

After applying the data inclusion rules, only a few exclusion criteria applied. Three reasons to throw out data emerged. An entire incident would be excluded if the plane landed at an improved runway. This would be regardless of distress or non-distress. This only applied to two cases. The second exclusion criterion was conflicting information. Often information could be obtained from AFRCC fields, AFRCC comment section, NTSB reports, or online. If conflicting information existed about one of the data collection subtasks (such as route or crash site elevation), then that specific element would be excluded. Finally, data elements of an incident would be excluded if missing information existed. Therefore, throughout this report different results are based upon different numbers of cases. The number of cases a result is based upon is stated in the "count" field.

The collected data fields from the AFRCC included 31 fields. These fields included the AFRCC incident number, mission number, general location (town or county) of the last known position, state of the last known position, latitude/longitude of the last known position, date, time, registration number of the aircraft, make/model of the aircraft, intended route, weather, secondary weather, number of subjects on board, number found alive, number found deceased, who found the aircraft, general location of find, latitude/longitude of find, find date, find time, source of radar data, FAA coordinates of last location, Mode 3 setting, Mode C reported altitude, second to last radar point coordinate, last change in vertical feet per minute, any predicted find coordinates, number of emergency locator transmitter updates, emergency locator transmitter coordinates, AFRCC controller comments, and if the AFRCC had added attachments to the file.

In order to obtain the distance traveled from the last recorded radar position, it was necessary to know the coordinates of the last recorded radar position and the find site coordinates. Radar plot coordinates were obtained from either 84th RADES or the FAA and both were recorded by the AFRCC. When radar data was reported by both sources, the 84 RADES data was used.

The NTSB maintains an online database of aviation accidents called the "Aviation Accident Database & Synopses."[17] Using the aircraft's registration number collected from the AFRCC data, it was possible to obtain the NTSB factual report—aviation, brief of accident, and probable cause reports. Data was then extracted from these reports and entered into the database. In several cases where the registration number had been entered incorrectly or was incomplete, it was possible to use other search parameters (date, location, type of aircraft, fatalities) to locate the reports. This also allowed updating the database with the correct registration number.

From the NTSB reports it was possible to add additional fields to the database and to verify information found in the AFRCC reporting system. The NTSB reports often provided information that might have been missing from the AFRCC report. The added fields included; NTSB ID number, flight part, flight type, light conditions, basic weather, ceiling, visibility, wind, precipitation, obscuration, flight hours total of pilot, flight hours in aircraft of pilot, flight hours instrument, pilot certification, flight plan, elevation of the crash site, crash bearing (magnetic), NTSB calculation of crash site to last radar, flight activity, terrain, accident cause, and NTSB find location coordinates. In some cases the NTSB had performed additional analysis of radar data and reported additional radar data than the AFRCC. However, the AFRCC data of the last known position from radar data was always used since this is the only data that operational search planners will have available at the time of an actual search.

When the NTSB supplied a crash site coordinate it was more likely to be based upon a GPS reading taken at the point of initial impact with the ground. Therefore, when find location coordinates came from both NTSB aviation accident investigation reports and from AFRCC reports, the NTSB coordinates were used.

Not all of the AFRCC incidents had an NTSB report. NTSB reports were obtained in 239 of the 262 incidents. Reasons for a missing report included the following: a more recent search where the report was not available at the time of data collection; a military flight; the incident did not meet the NTSB criteria for making a report; or insufficient information to locate a report.

Additional fields were added for calculations and data obtained from the source data of the AFRCC and NTSB. All of the various distances needed to be calculated from the various coordinates using batch processing of coordinates from GPSwaypoints.com.za, which uses great circle calculations estimated to be accurate to one part in one million. Aircraft were placed into the appropriate category (e.g., twin engine) after viewing a photograph of the aircraft using Google images. Airport and navigational aid (navaid) identifiers were verified

using www.airnav.com, if required. Flight routes were entered into www.skyvector.com to determine the route length and also to verify all waypoints. Google Earth was also used to determine whether the aircraft's find location plotted to an airport and the elevation of the crash site. Coordinates were provided in at least four different systems: decimal degrees (DD.DDD), degrees decimal minutes (DD MM.MMM), degrees minutes seconds (DD MM SS.SS), or Universal Trans Mercator. All coordinates were converted to the decimal degree format using Degree Format Convertor from GPSwaypoints.co.za. USGS 1:24,000 topographic maps used to determine the highest ridge or mountain summit were also obtained using ExpertGPS (TopoGrafix, Stow, MA).

The search duration (h:min) was calculated as the difference between the time the aircraft was last seen and when it was located. In the AFRCC records, the time last seen was not based upon the last radar track but rather on when the aircraft departed. In several incidents, the aircraft was not located during the initial search effort. These caused durations that in some cases exceeded 4000 h. Therefore, for the purpose of calculating averages for instrument flight rules (IFR), visual flight rules (VFR), and no flight plans, incidents with durations of greater than 2 wk (336 h) were excluded.

The heuristic for determining which particular flight characteristic to select for displaying probable Euclidian distance quartile rings from the last radar plot was based upon each of the following flight characteristics: aircraft type, flight plan, meteorological conditions, flight phase, final flight characteristic, and elevation changes. These characteristics were evaluated for statistical significance. Among the factors that achieved statistical significance with $P < 0.05$, the probability density (P_{den}) was evaluated by the summation of the P_{den} within the 50% ring, the 50–75% annulus, and the 75–95% annulus. This was sorted in rank order so that the flight characteristic with the largest summed P_{den} would be examined first.

RESULTS

A total of 260 missing aircraft incidents involving 509 persons were collected that met the inclusion/exclusion criteria. A mortality rate of 89% was found. Radar information was available for 216 incidents (83%). Among the missing aircraft, 241 incidents indicated the type of flight, of which 95% were Part 91, 4% were Part 135, and 1% were Part 137. The majority of search incidents took place in mountainous terrain (148; 57%), followed by flat/hilly (104; 40%), and over water (8; 3%). The average time to locate the missing aircraft was 42:24 (h:min) if no flight plan was filed, 37:18 for VFR, and 13:06 for IFR or flight following. The overall distribution of where missing aircraft were located is shown in **Fig. 1**.

The distance traveled from the last recorded radar position was obtained from 216 incidents (**Table I**). The descriptive statistics of count (*N*), quartiles, 95%, average, and standard deviation (SD) are provided. Search and rescue practitioners often use the 95% distance (based upon $2\sigma + x$) as the practical limit
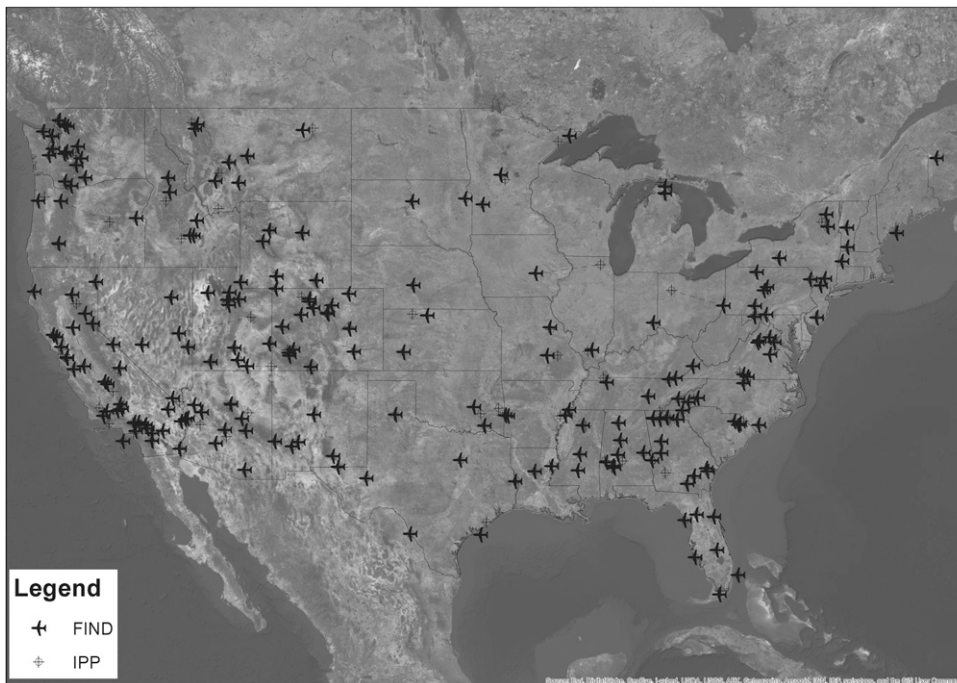
Fig. 1. Spatial distribution of location of missing aircraft along with last radar plot.

of where to search for ground searches. All distances are given in nautical miles unless otherwise stated. The first column (All) represents the entire dataset. For the entire dataset it can be seen that half (median) the aircraft are located within 0.8 nmi from the last radar position. This represents a significant clustering of the probability of containment (POC). The overall median has a probability density of 0.25 POC/nmi². The probability density is high enough to warrant a ground search if the terrain or conditions do not allow a high probability of detection in an air search. The overall spatial distribution of crash site locations relative to the last radar plot (center of graph) is shown in **Fig. 2**. No statistical differences were seen in distances among the four cardinal quadrants (ANOVA $P = 0.91$) or between the NS versus EW quadrants (Kolmogorov-Smirnov $P = 0.88$).

The first modifying factor that was examined was the type of aircraft. The table shows the results from helicopters, jet aircraft, twin (propeller), and single (propeller) engine aircraft. Some clear differences appear between the various types of aircraft. An ANOVA between the four groups just missed statistical significance ($F = 2.463$, $P = 0.063$). No significant difference was seen between single and twin engine propeller aircraft

using a Kolmogorov-Smirnov test ($P = 0.85$) nor between jets and propeller aircraft ($P = 0.096$).[11] Jet aircraft tend to be carefully flight followed and can be significantly above ground level (AGL), where radar coverage is excellent. Helicopter incidents show the largest SD. They could be found quite close to the last radar plot (25% within 0.2 nmi) or much further out. A working hypothesis that helicopters typically fly at low AGL altitudes, making it easier to fly out of radar coverage long before the actual incident.

A major factor in aircraft incidents is the weather. The NTSB accident report classified the weather as either instrument meteorological conditions (IMC) or visual meteorological conditions (VMC). In addition, the NTSB reported if icing conditions existed.

It appears that the aircraft flying in IMC are located closer to the last radar position than in VMC (**Table II**), with the 25%, 50%, and 75% annulus being roughly half the distance. However, statistical outliers appear to be more common for flights during IMC. A significant difference was seen between icing conditions and VMC using a Kolmogorov-Smirnov test ($P = 0.032$), but no difference was seen between VMC and IMC ($P = 0.158$).
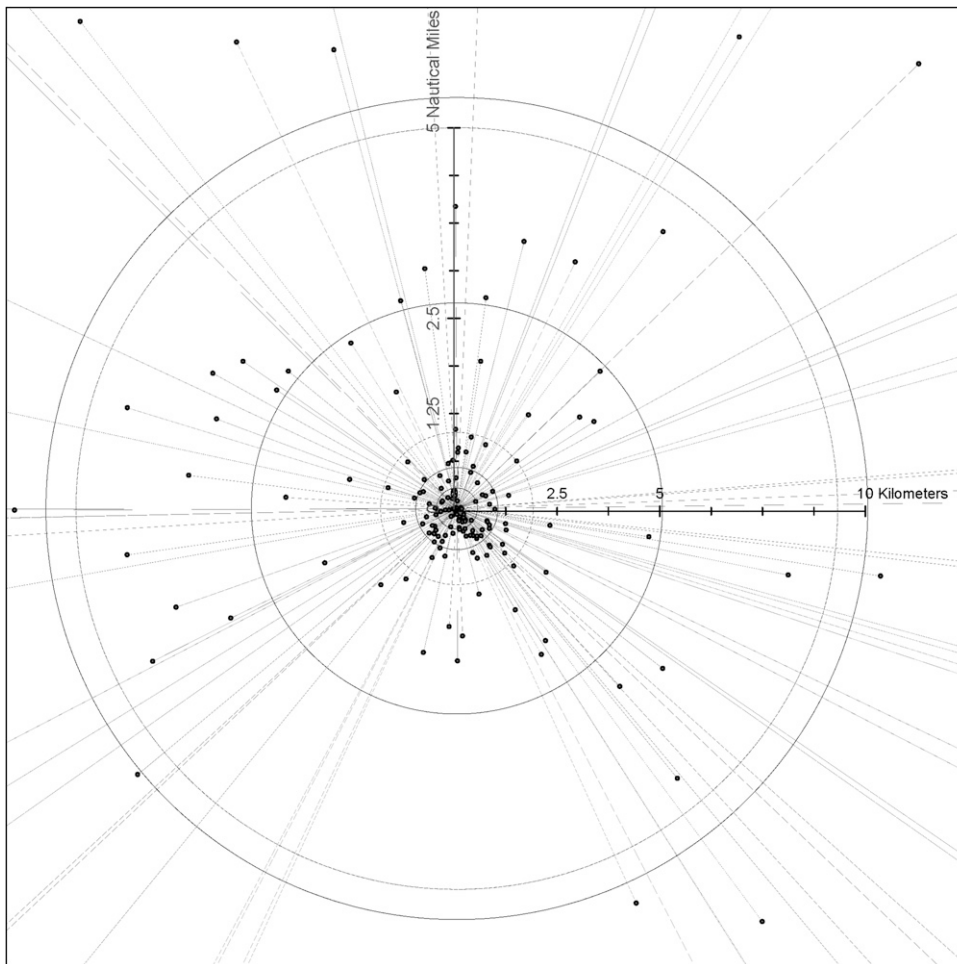
Another significant factor may involve the type of flight plan profiles followed. The database recorded four types of flight plan profiles: flight plans filed under IFR, flight plans filed under VFR, no filed flight plan (none), and VFR flights with flight following requested. Requests for flight following are made during the flight; however, the pilot may or may not have filed a flight plan. Although these flights are conducted under visual rules, flight followed aircraft were placed with instrument rules aircraft for statistical analysis purposes.

Aircraft flying under instrument rules were found significantly closer to the last radar plot than visual rules using a Kolmogorov-Smirnov test ($P = 0.007$). This result it not too unexpected: since instrument rules aircraft are issued a discrete code, it is much easier to find the correct radar track for these aircraft. When no flight plan is filed, the aircraft is typically found significantly closer than visual rules (using the Kolmogorov-Smirnov test, $P = 0.032$).

The NTSB report classified the flight phases of when different

Table I. Distance (nmi) of Crash Site from Last Radar Fix for All Data and by Aircraft Type.

	ALL	HELICOPTER	JET	TWIN	SINGLE
N	216	11	6	21	177
25%	0.4	0.2	0.6	0.5	0.4
50%	0.8	3.2	1.5	1.5	0.7
75%	5.5	17.6	2.4	7.2	4.8
95%	45.4	105.7	4.2	24.6	42.5
Avg.	7.4	22.0	1.7	6.2	6.8
SD	19.0	41.8	1.2	9.2	17.8

Fig. 2. Spatial distribution of crash location (black dot) to the last radar plot (center).

what the aircraft was doing during the last minute of recorded flight. The terms used during this analysis were straight, straight (and level), straight and descending, bearing right or left (turn of 5-45°), turning right or left (turn of 45-90°), hooking right or left (turn of >90°), and spiraling right or left (turn of >180° and it crosses over itself). For this analysis, only the major terms were used and right and left differences were ignored. The flight characteristics were determined by looking at a map of the plots looking at only the horizontal aspects of flight. Only straight and descending factored in a vertical component. An ANOVA showed a difference exists among the categories ($P = 0.027$).

While flight characteristics looked at the horizontal characteristics of the last few plots, the change in feet per minute (FPM) looked at the vertical change in the last plot. Change in FPM were obtained from Mode C transponder returns, which are only precise to 100 ft. For the sake of making tables, the data was placed into bins, with the first bin containing incidents where the descent in FPM was greater than 2000 ft (**Table IV**). The second bin contained descents of 1000-2000 FPM, the third bin 1-1000 FPM, in the fourth bin the flight was level (0 FPM), and the last bin contained 8 cases where the aircraft was climbing. No significant differences were seen using an ANOVA test among the different bins ($P = 0.11$). However, using the Kolmogorov-Smirnov test, a significant difference was seen between the descent rate of >2000 FPM and 0 FPM ($P < 0.001$) and 999-1 FPM ($P < 0.001$). Only eight cases exist in the database where the aircraft was climbing; Kolmogorov-Smirnov testing was not possible.

factors or causes of the accident occurred. With a radar track available, it should be possible for a skilled search planner to determine the phase of flight that is occurring at the time of the last radar plot. Some phases of the flight did not have sufficient incidents and were grouped with the next best match. The phases of flight that were examined were climb, cruise, maneuvering, descent, and approach. An ANOVA showed that none of the phases of flight (**Table III**) had a statistically significant difference ($P = 0.88$).

In most cases, the radar data is not restricted to the last radar plot, but instead tends to show the last minute, last 5 min, or even the entire flight; therefore, it is possible to characterize

Table II. Distance from Last Radar Fix from Crash Site (in nmi) for Type of Flight Plan and Different Meteorological Conditions.

	FLIGHT PLAN			METEOROLOGICAL CONDITIONS		
	IFR	**VFR**	**NONE**	**IMC**	**VMC**	**ICING**
N	79	42	80	102	112	11
25%	0.3	0.5	0.4	0.3	0.4	0.1
50%	0.5	3.0	0.8	0.7	1.3	0.4
75%	3.1	13.1	9.6	3.1	7.1	0.8
95%	14.3	55.8	58.1	47.9	28.9	1.7
Avg.	2.9	10.4	9.8	6.3	6.5	0.5
SD	5.7	22.7	24.1	20.8	11.2	0.6

Table III. Distance (nmi) of Crash Site from Last Radar Fix by Flight Phase.

	FLIGHT PHASE					FLIGHT CHARACTERISTIC					
	CLIMB	CRUISE	MANEUVER	APPROACH	DESCENT	STRAIGHT	STRAIGHT DESCEND	BEAR	TURN	HOOK	SPIRAL
N	14	31	42	94	17	67	14	10	13	34	13
25%	0.5	0.4	0.4	0.3	0.1	0.7	0.1	0.1	0.5	0.3	0.3
50%	0.7	0.6	0.8	0.8	0.5	2.8	0.3	0.7	0.7	0.4	0.7
75%	5.3	7.4	7.0	3.6	2.6	13.9	0.5	1.0	2.1	1.5	6.8
95%	14.6	20.4	25.1	51.4	22.0	65.4	15.6	17.1	3.6	6.3	13.6
Avg.	3.6	5.0	6.1	7.3	4.1	12.7	2.1	2.9	1.2	1.4	3.7
SD	5.5	7.7	9.5	22.1	8.9	26.4	6.8	7.1	1.2	2.4	5.0

DISCUSSION

The typical missing aircraft profile involves flying under Part 91 (95%), in a single engine aircraft (82%), flying without a flight plan (40%) or an IFR flight plan (39%), over mountainous terrain (57%), in the approach phase (47%), did not survive (89%), and is found within 0.8 nmi of the last radar plot (50%). The AFRCC was able to obtain a radar track in 83% of the incidents. This percentage might be even higher if the aircraft has been quickly located; then efforts to determine the track will cease. The overall distribution of missing aircraft is similar to the spatial distribution of fatal crashes described by Grabowski et al.[10]

No significant differences were seen among the different types of aircraft for the distances from the last radar plot. However, jets just missed statistical significance ($P = 0.096$), most likely due to a small sample size ($N = 6$). From an operational perspective, the 4.2 nmi 95% ring is different than the 19.0 nmi 95% ring seen for the entire database. While the median ring was greater than the entire database, this is not unexpected for a faster moving aircraft.

The meteorological conditions were significant if icing conditions were present. The possibility of icing conditions was determined by the NTSB, but during actual search incidents could be assigned a probability as a scenario. When icing conditions existed, 95% of aircraft were found within 1.7 nmi of the last radar position. No significant difference was seen between IMC and VMC conditions.

While no significant difference was found in the phase of flight (climb, cruise, maneuver, approach, or descent), the most common phase was during the approach (47%). In most cases, not only is the last radar position available, but many of the previous radar returns have been obtained. Since each radar return is time coded, it is possible to characterize the final flight characteristics as determined by radar. Turns and hooks appear to

be the best predictor of finding the aircraft nearby, all the way out to the 95% ring. Descending or bearing to the left or right also predicts shorter distances. Straight and descending had a significantly high probability zone, with 75% of the incidents within 0.5 nmi. Spirals demonstrate some variability. If an aircraft was flying straight (and usually level), that proved to be a poor predictor of the distance from the last radar plot.

One of the best predictors of the aircraft being located near the last radar position was when its final descent rate exceeded 2000 ft/min. If this was the case then 95% of the aircraft were found within 1.8 nmi. Descents of 1-999 ft/min often represent normal descent rates for landing. Also, the limited precision of transponder reported altitudes means the plane could have been flying level, but reported as descending for the last two Mode C reports. The distances are slightly greater than the median of 0.8 seen for the entire database. Level flight (0 ft/min) also shows a median greater than the median value of the entire database.

The report clearly defined that the probability of finding the aircraft close to the last radar plot is significant. In fact, 50% of all aircraft are found within 0.8 nmi of the last plot. This gives a potential search area of only 2 nmi^2—a size (depending upon terrain and weather) easily searched on the ground, even at night. However, the study could easily be improved by examining several other factors. Radar information depends upon the radar forensic analyst finding the correct track that relates to the correct aircraft, then finding the last possible track, often from many segments that have gaps. The input of the analysts of their confidence in the track is clearly needed. The simple proxy for "confidence" in the database was the 40 incidents in which the radar analyst forwarded a formal prediction of where the aircraft might be found. Analysis of those predictions showed 68% were found within 1 nmi and 76% were within 2 nmi. The 75% quartile for the overall database was 5.5 nmi. This might be even more important if two or more candidate tracks are possible. While the tracks could be weighted evenly from a statistical point of view, it might be more useful to have the analyst weigh the probability.

Ultimately, statistical information must be translated into tactical decisions by the search

Table IV. Distance (nmi) of Crash Site from Last Radar Fix by Vertical ft/min Rate.

	>2000 ft/min	1999-1000 ft/min	999-1 ft/min	0 ft/min	CLIMBING
N	34	14	18	28	8
25%	0.2	0.4	0.5	0.6	0.3
50%	0.4	0.6	1.5	1.8	0.9
75%	0.5	3.6	6.6	9.3	2.4
95%	1.8	15.7	101.2	27.7	6.8
Avg.	0.5	3.3	15.4	7.0	1.9
SD	0.6	6.2	42.9	10.3	2.4

planner. In many cases this involves simple paper and pen technology. Even the utilization of more sophisticated optimal allocation of resources algorithms (Charnes Cooper) requires assigning probability of area.[6] Therefore, the search planner faces the task of selecting the most appropriate model or combining them all. We propose a simple algorithm based upon factors that were statistically significant and designed to maximize the probability density. This would allow the least amount of effort to achieve the greatest amount of success.

The factors that were determined to be statistically significant included the type of flight plan (IFR, VFR, or none), the meteorological conditions (if icing conditions were present), the final flight characteristic (straight, straight and descending, bearing right or left, turning, a hook, or a spiral), and vertical changes (descent greater than 2000 ft/min). The probability density for each factor was determined as described in the Methods section. The summed P_{den} values were then shortened to create the algorithm shown in **Fig. 3**. The last three factors (no flight plan, straight flight, and VFR flight plan) had a lower P_{den} value than the overall score. In particular, a final flight characteristic of flying straight ($\Sigma P_{den} = 0.021$) or a VFR flight plan ($\Sigma P_{den} = 0.018$) had a lower summed P_{den} value by a factor of more than 10 compared to the entire database ($\Sigma P_{den} = 0.252$). While some aircraft were still found relatively close for these conditions, search planners would be well advised to look at all factors, including the range of radar coverage prior to committing ground resources.

The approach used in this study was to attempt to identify factors that result in more probability being found closer to the last radar plot. An equally valid approach is to look at factors that might identify when the last plot has nothing to do with the aircraft final location. Such a measure would help to avoid putting too much emphasis on the last radar track. A formal study of all those incidents where the aircraft was not found near the last radar plot should look at radar coverage. This study already identified that straight and level flight might be another good predictor of a "non-relevant" last radar plot. However, it is noteworthy that two cases mention that the last radar plot occurred at a point of known end of coverage, but the aircraft was found near those plots. It would be prudent to eventually examine the

actual model of aircraft, if the aircraft entered a thunderstorm, day or night light conditions, the visibility, the ceiling, the last radar's position AGL altitude, and certain key scenarios.

The ultimate goal of search and rescue is to locate and rescue the subject. To find the subject, search resources must be placed in the correct location. Formal search theory can help determine the placement of resources, but it is dependent upon identifying how much probability of containment exists in each search grid. Therefore, it is of paramount importance to develop a model that correctly allocates probability into different areas contained in the search area. The raw data and preliminary results presented here are the foundation to achieving this goal. However, radar data is not the only source of developing probability models for location. Additional models from cell phone forensics and Automatic Dependent Surveillance will become increasing important. In the Air France Flight AF447, it was the Aircraft Communications and Addressing Reporting System broadcast that provided the critical information. However, the full value of that information was not realized until a formal probability map was created.[22] Since humans by nature are poor at visualizing probability and statistics, it is imperative to provide the information in a way that is easy to digest, visualize, and allows for making operational decisions.

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REFERENCES

1. Abi-Zeid I, Frost JR. SARPlan: a decision support system for Canadian Search and Rescue Operations. Eur J Oper Res. 2005; 162(3):630–653.
2. Abi-Zeid I, Nilo O, Schvartz S, Morin M. Towards a knowledge-based system prototype for Aeronautical Search and Rescue Operations. In: 2010 13th Conference on Information Fusion (FUSION) (pp.). New York: IEEE; 2010:1-8.
3. AFRCC 2013 Annual Report. [Accessed September 7, 2015.] Available from http://www.1af.acc.af.mil/shared/media/document/AFD-140411-034.pdf.
4. Baker SP, Shanahan DF, Haaland W, Brady JE, Li G. Helicopter crashes related to oil and gas operations in the Gulf of Mexico. Aviat Space Environ Med. 2011; 82(9):885–889.
5. BEA 2012 Final Report: On the Accident on 1st June 2009 to the Airbus 330-203 Registere F-GZCP Operated by Air France Flight AF 447 Rio de Janeiro-Paris. Le Bourget (France): Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile; 2012. [Accessed September 7, 2015.] Available at http://www.bea.aero/en/enquetes/flight.af.447/rapport.final.en.php.
6. Charnes A, Cooper WW. The theory of search: optimum distribution of search effort. Management Science 1958; 5(1):44-50.
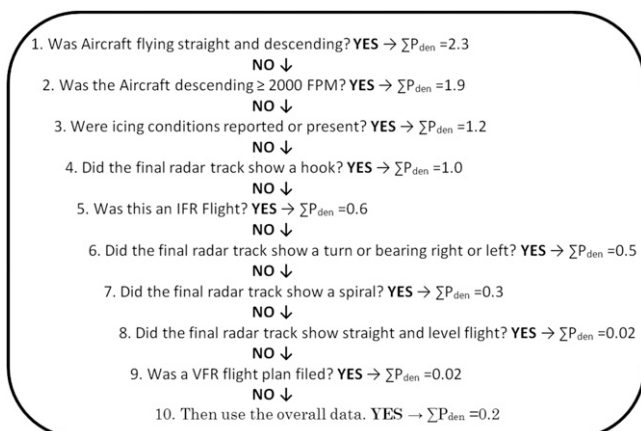
Fig. 3. Hierarchy of flight characteristics to provide best ΣP_{den}.

1. Was Aircraft flying straight and descending? **YES** → ΣP_{den} =2.3
   NO ↓
2. Was the Aircraft descending ≥ 2000 FPM? **YES** → ΣP_{den} =1.9
   NO ↓
3. Were icing conditions reported or present? **YES** → ΣP_{den} =1.2
   NO ↓
4. Did the final radar track show a hook? **YES** → ΣP_{den} =1.0
   NO ↓
5. Was this an IFR Flight? **YES** → ΣP_{den} =0.6
   NO ↓
6. Did the final radar track show a turn or bearing right or left? **YES** → ΣP_{den} =0.5
   NO ↓
7. Did the final radar track show a spiral? **YES** → ΣP_{den} =0.3
   NO ↓
8. Did the final radar track show straight and level flight? **YES** → ΣP_{den} =0.02
   NO ↓
9. Was a VFR flight plan filed? **YES** → ΣP_{den} =0.02
   NO ↓
10. Then use the overall data. **YES** → ΣP_{den} =0.2

7. Desmarais J. Search planning guidance for use in general aviation missing aircraft searches in the continental United States. Maxwell Air Force Base (AL): Civil Air Patrol National Headquarters; 2000. [Accessed September 7, 2015]. Available from http://members.gocivilairpatrol.com/media/cms/Missing_Aircraft_Search_Methodologies_Paper.pdf.

8. de Voogt AJ, Van Doorn RA. Sports aviation accidents: fatality and aircraft specificity. Aviat Space Environ Med. 2010; 81(11):1033–1036.

9. Frost JR, Stone LD. Review of search theory: advances and applications to search and rescue decision support (No. CG-D-15-01). Fairfax (VA): Soza and Company LTD; 2001.

10. Grabowski JG, Curriero FC, Baker SP, Li G. Exploratory spatial analysis of pilot fatality rates in general aviation crashes using geographic information systems. Am J Epidemiol. 2002; 155(5):398–405.

11. Kirkman TW. Statistics to use. 1996 [Accessed September 7, 2015]. Available from http://www.physics.csbsju.edu/stats/.

12. Koopman BO. Search and screening: general principles with historical applications. New York: Pergamon Press; 1980.

13. Li G, Pressley JC, Qiang Y, Grabowski JG, Baker SP, Rebok GW. Geographic region, weather, pilot age and air carrier crashes: a case-control study. Aviat Space Environ Med. 2009; 80(4):386–390.

14. NASA. Air Search and Rescue Instructions. [Accessed on September 7, 2015.] Available from http://worldwind.arc.nasa.gov/java/apps/SARApp/help/v6/SARHelp.html.

15. National Search and Rescue Committee. Land Search and Rescue Addendum to the National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual Version 1.0; 2011. [Accessed September 7, 2015.] Available from: http://www.uscg.mil/hq/cg5/cg534/nsarc/Land_SAR_Addendum/Published_Land%20SAR%20Addendum%20(1118111)%20-%20Bookmark.pdf.

16. National Transportation Safety Board. National Transportation Safety Board Safety Recommendation A-09-102 and A-09-103. Washington (DC): NTSB; 2009. [Accessed on September 7, 2015.] Available from http://www.ntsb.gov/doclib/recletters/2009/A09_102_103.pdf.

17. NTSB Accident Database & Synopses. [Accessed September 7, 2015.] Available from http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx.

18. O'Hare D, Chalmers D, Scuffham P. Case-control study of risk factors for fatal and non-fatal injury in crashes of civil aircraft. Aviat Space Environ Med. 2003; 74(10):1061–1066.

19. Reveley MS, Briggs JL, Evans JK, Sandife CE, James SM Causal factors and adverse conditions of aviation accidents and incidents related to integrated resilient aircraft control. Washington (DC): NASA; 2010. Report No.: NASA/TM–2010-216261.

20. Saunders PH. A new search method based on an analysis of air distress cases: 1981–1986. CFB Trenton, Astra, Ontario (Canada): Department of National Defense, Canada; Operational Research Branch, Air Transport Group Headquarters; 1987. ATGOR Staff Note 2/87.

21. Shao BS, Guindani M, Boyd DD. Fatal accident rates for instrument-rated private pilots. Aviat Space Environ Med. 2014; 85(6):631–637.

22. Stone LD, Keller CM, Kratzke TM, Strumpfer JP. Search for the wreckage of Air France flight AF 447. Stat Sci. 2014; 29(1):69–80.

23. Syrotuck WG. In: Syrotuck JA, editor. Analysis of lost person behavior: an aid to search planning. Mechanicsburg (PA): Barkleigh Productions, Inc.; 2000.

24. Syrotuck W, McIver M. Preliminary investigation. In: Syrotuck W, editor. An introduction to land search: probabilities and calculations. Mechanicsburg (PA): Barkleigh Productions, Inc.; 1975.

25. Taneja N, Wiegmann DA. Analysis of injuries among pilots killed in fatal helicopter accidents. Aviat Space Environ Med. 2003; 74(4):337–341.
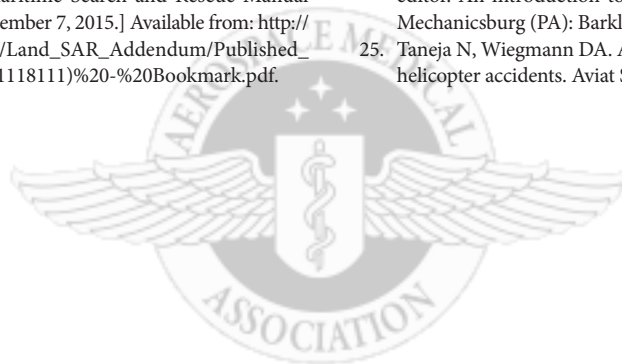
Evaluating Lost Person Behavior Models

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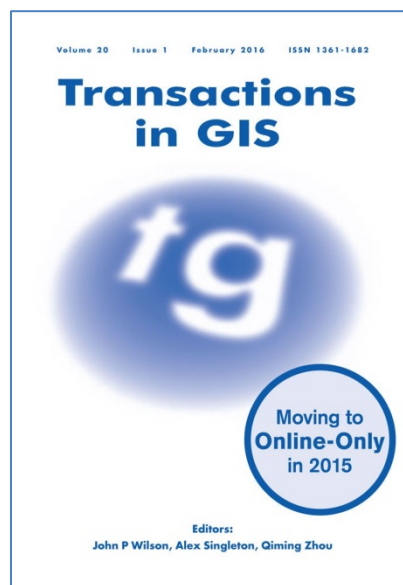
Evaluating Lost Person Behavior Models

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Abstract

US wilderness search and rescue consumes thousands of person-hours and millions of dollars annually. Timeliness is critical: the probability of success decreases substantially after 24 hours. Although over 90% of searches are quickly resolved by standard "reflex" tasks, the remainder require and reward intensive planning. Planning begins with a probability map showing where the lost person is likely to be found. The MapScore project described here provides a way to evaluate probability maps using actual historical searches. In this work we generated probability maps the Euclidean distance tables in (Koester 2008), and using Doke's (2012) watershed model. Watershed boundaries follow high terrain and may better reflect actual barriers to travel. We also created a third model using the joint distribution using Euclidean and watershed features. On a metric where random maps score 0 and perfect maps score 1, the Euclidean distance model scored 0.78 (95%CI: 0.74–0.82, on 376 cases). The simple watershed model by itself was clearly inferior at 0.61, but the Combined model was slightly better at 0.81 (95%CI: 0.77–0.84).

1 Introduction

Searching can be arduous, time consuming, and expensive. These characteristics justify "taking the search out" of search and rescue (SAR), a worthy but unreachable goal: some search always remains, and search requires planning. The probability of survival in land-search decreases with time (Pfau 2011). Good planning makes search more efficient, reducing costs and saving lives. The first step is deciding where to search: some areas are more likely than others. In fact, some areas are so much more likely that >90% of searches are resolved within a few hours based on "reflex" tasks to the high-probability areas (Koester 2008). However, the remaining cases require and reward explicit planning using methods first developed in WWII (Koopman 1980). Planning begins with a probability map showing where the lost person is likely to be, allocates search effort to minimize expected time to find, and updates the map after each operational period to account for completed searches, clues found, and possible subject motion. In wilderness search (WiSAR) this is often either intuitive or manual, but with increasing use of Geographic Information Systems (GIS) planning tools, WiSAR can create and update detailed probability maps (Doherty et al. 2014). But how to tell a good map from a poor one?

In this article we generate and compare several probability maps for hundreds of historical WiSAR incidents for which there were good initial and final coordinates. The incidents come from the International Search and Rescue Incident Database (Koester 2010). Maps are scored using a simple and robust metric from crime-mapping (Rossmo 1999). While there are a few papers on producing WiSAR probability maps (see for example: Castle 1998; Soylemez and Usul 2006; Sarow 2011; Lin and Goodrich 2010; Ferguson 2013; Doherty et al. 2014) there has been no evaluation of the relative accuracy of different methods. This article is the first to establish a performance baseline we hope will be surpassed repeatedly.

In practice, the most common way to assign probabilities to search regions is with subjective estimates based on quartile distance statistics, particularly the summary statistics found in Koester (2008): a simple 'bulls-eye' formed by the 25%, 50%, 75%, and 95% probability circles. Thus the distance ring model serves as a baseline. We compare it to a relatively recent watershed model (Doke 2012; Doherty et al. 2014), and a novel combination of the two.

The Introduction briefly reviews WiSAR costs and the use of probability maps in WiSAR. Section 2, Scoring, introduces the MapScore website, Rossmo's metric, and its desirable properties. Section 3, Data and Methods, introduces the models. Section 4, Results, evaluates these models. Section 5, Discussion, provides a brief conclusion and recommendation for future work.

1.1 Cost and Time

In the US, the National Park Services (NPS) alone conducts thousands of search and rescue operations annually. According to NPS and the US Park Police (2012), the NPS conducted 4,080 SAR operations at a total cost of $5.3 million, or roughly $1,375 per mission. Figure 1 shows the increasing costs for SAR operations over the past several years (1995–2012).

The price appears to be rising faster than inflation: from 1992 to 2007 the NPS responded to 65,439 incidents at an average cost of $895 per operation (Heggie and Amundson 2009). However, from 2000 to 2012 the NPS responded to 53,351 incidents at an average cost of $1,163. In constant 2013 US dollars, the average increase is about $160 per case. Nearly half the total cost was overtime; the remainder was mostly aircraft (Heggie and Amundson 2009). Yosemite National Park alone accounted for 25% of the total costs ($1.2 million).
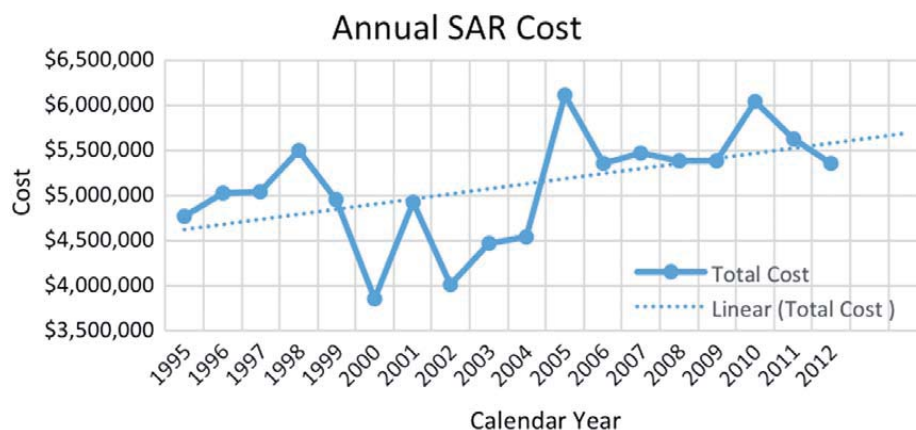
Figure 1   Annual cost for Search and Rescue operations conducted by the National Park Service at constant 2013 dollars
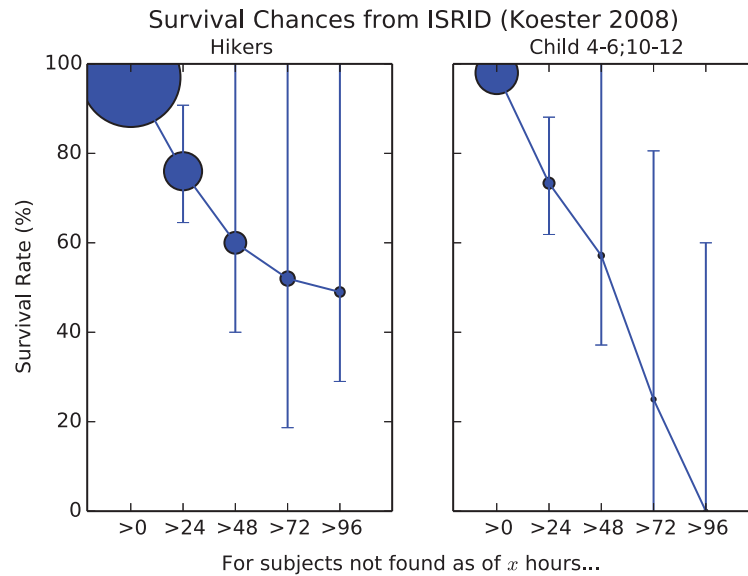
Figure 2 Probability of successful rescue by time, for Hikers (left) and Children (right). From data in (Koester 2008). Marker size indicates number of cases. Points are drawn at the observed frequency; Error bars show 95% range based on smoothed resampling. The central tendency is clear: time is not on your side.

Time is the other key issue. Figure 2 shows the decreasing chances of successful rescue over time for hikers and children aged 4–6 years-old (Koester 2008; Pfau 2011). The decline is due to a combination of injuries, exposure, exhaustion, and dehydration. The larger the search area, the longer it takes to search. Therefore, limiting the search area substantially improves the chance of rescue.

1.2 Probability Maps

Mathematical search theory (Koopman 1980) takes a probabilistic approach because, by definition, the location of any search object is unknown. Some of the earliest documented searches divided the search region into smaller cells, and assigned probabilities to each of those cells based on a structured mix of subjective and objective information. For example, Figure 3 shows maps from the 1967 search for the USS Scorpion (Richardson and Stone 2006) and Figure 4 the 2009 Search for Air France Flight 447 (BEA 2012). Both have been recounted in McGrayne (2012).

Search theory has advanced considerably since its origins in World War II, and modern maritime search planning software like SAROPS (Kratzke et al. 2010) incorporate sophisticated motion models and path planning for searchers. There is nothing comparable for WiSAR. WiSAR has been slow to adopt search theory, in part because good probability maps have been unavailable, and because probability of detection varies dramatically with small-scale changes in terrain and vegetation. (There are also institutional reasons, such as the lack of central authority or central funding for WiSAR.)

Maritime probability maps are conceptually simple: there is a physics of ocean drift, however complicated. There is no equivalent for lost person behavior. Nevertheless, early work by Syrotuck (1976/2000) showed that lost persons generally stayed very close to the initial planning point (IPP): 60% were found within two miles (Euclidean or crow's-flight distance). Based on his 242 cases from New York and Washington states, Syrotuck formulated a
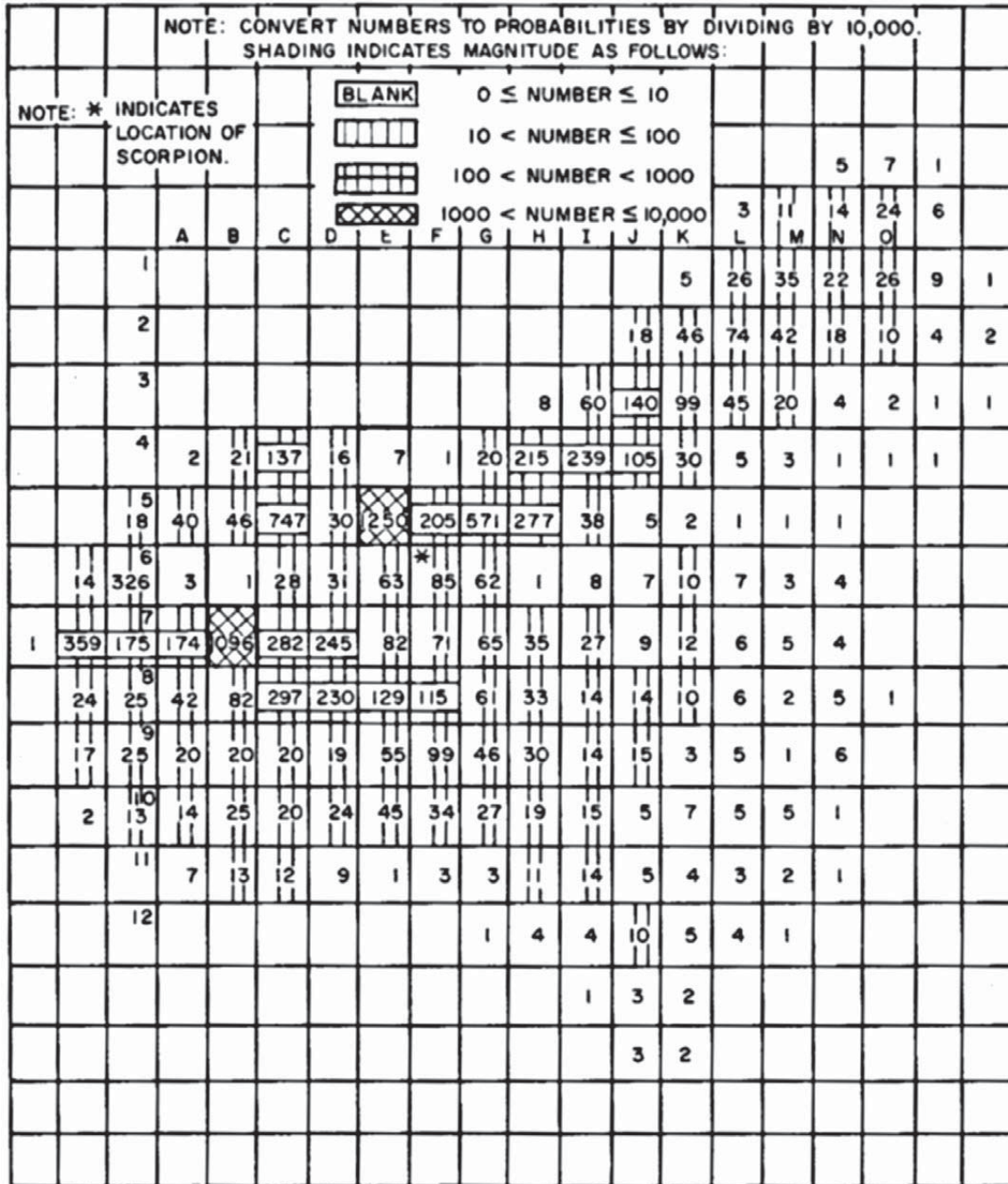
Figure 3 Composite probability map for the USS Scorpion. Used with permission from (Richardson and Stone 2006)

"ring" model, by noting the 25%, 50%, 75%, and 95% zones for eight subject categories including: Hunters, Hikers, Elderly, and Child.[1] Subsequent studies over the last 37 years have collected more data from various regions in the US and abroad. Recently, Koester (2008, 2010) created a unified database containing thousands of cases worldwide. For each of his categories he reported summary statistics for: Euclidean distance, track offset, dispersion angle, find location, scenario, mobility, and survivability.
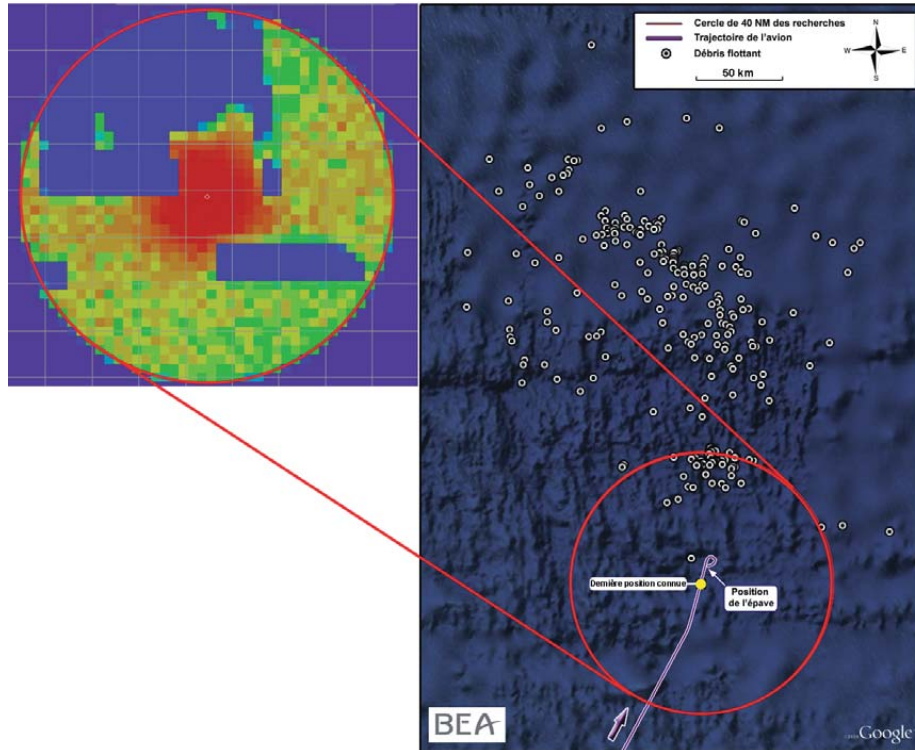
Figure 4   Air France 447 last known point (LKP, center of circles), floating debris (dots), and Phase III probability map assuming inoperational pingers and accounting for searches in Phase I and II (left inset). The wreckage (arrow) was found about 6.5 NM from the LKP in the red high-probability area. Probabilities decrease from red to orange to yellow to green to blue. Drift map from (BEA 2012). Inset used with permission from (Stone et al. 2011).

Both Syrotuck and Koester create simple probability maps (like the distance-ring model) directly from the summary statistics. In effect, this assumes that by the time the search has started, the subject is not moving appreciably. The surprisingly small distances traveled suggest this is a pretty good assumption in many cases. Nevertheless, ideally the models would account for motion during the search. Several motion models have been formulated (Castle 1998; Lin and Goodrich 2010), which treat the subject's movement as a stochastic process governed by transition matrices which include, for example, a subject's preference for uphill/level/downhill, or moving from one kind of trail/vegetation to another, or simply going straight versus turning.

These approaches generate a probability map by dropping thousands of simulated subjects on the map around the IPP, and running a large Monte Carlo simulation. The advantage of this approach is that the map evolves with time. The disadvantage is that it is hard to fit the extra parameters because, almost by definition, we do not have any information on the lost person's actual trajectory. Progress will depend on having a good method for scoring probability maps, so the fitting algorithms can improve.

In this article, we measure the performance of the baseline Euclidean distance model, and a recent "watershed distance" model (Doke 2012; Doherty et al. 2014) that counts the number of watersheds crossed by the lost person. Both Euclidean and watershed distance models do well because most lost persons do not travel very far.

2 Scoring

2.1 Genesis of MapScore

Rather than scoring the cases offline, MapScore provides a public website with a live leaderboard and the potential to inspire friendly competition among potentially very different approaches. The project began after discussion with the Brigham Young (BYU) WiSAR team about how to compare their Bayesian motion model for lost person behavior (Lin and Goodrich 2010) with our multivariate models. How did either compare with the simple models implied by summary statistics? The BYU team helped fund initial work on what is now the MapScore website (Twardy et al. 2012; Twardy 2012, http://mapscore.sarbayes.org), and this article reports baseline scores for a Euclidean distance-ring model and a simple cost distance model. The chosen score is based on the probability density assigned to the find region.

Search theory has shown that expected search time is minimized by allocating resources to maximize the "probable success rate", or the amount of probability that we "sweep up" with every unit of time (Stone 2007; Koopman 1980; Frost 1996). In theory we might want to score a map based on expected time to find the subject, given optimal plans made on the basis of the probability map and a map of detection indices for each resource. However, that would require contentious assumptions about the resources at hand, how they can be used, and their largely unknown detection indices. For purposes of portably comparing probability maps, we can assume a single resource with detection equal in all regions. Then allocating resources according to the probability density or *Pden* is optimal, and we can use a metric based only on *Pden*. *Pden* is defined as the probability per unit area. The distinction between *Pden* and *POA* (probability of area) matters because many methods assign probabilities to regions of varying size. For example, the distance ring model assigns 25% probability both to the small region around the IPP and to the entire search region beyond the 75% ring. We would prioritize the former because the *Pden* is much higher. But if the final scored map has been rasterized into equal-sized pixels with values equal to the probability contained in that area, then POA and *Pden* are the same. The MapScore metric is suitable for rasterized probability maps.

2.2 Scoring Metric

Rossmo (1999) developed a robust metric *R* to compare probability maps for crime forecasting. The metric is rank-ordered, and a good model will assign higher values to the actual find location, compared with other areas. It measures the proportion of pixels that are assigned higher values than the actual find location. The absolute value depends on the image size, so MapScore uses a fixed size and scale. For each case, we place the IPP at the exact center of a $5,001 \times 5,001$ pixel map, where each pixel is 5 m $\times$ 5 m wide. At this resolution, models can use features as small as 10 m without aliasing effects. At this size, the map extends 12.5 km in each cardinal direction from the IPP, which on average includes at least 95% of the search cases. Models assign pixels a brightness value corresponding to the estimated probability density at that pixel. (Most models will be much coarser than individual pixels, so they will divide the total probability in a region by the number of pixels in that region.)

Let p equal the probability assigned to the actual find location, N be the total number of pixels in the image, n the number with probability greater than p, and let m be the number of pixels with probability equal to p. Then we define:

$$r = \frac{n + m/2}{N} \tag{1}$$

The value of *r is* then rescaled, so that the worst possible score is −1, and the best is +1:

$$R = \frac{.5 - r}{.5} \tag{2}$$

Because we corrected for pixels whose probability is equal to *p*, uniform (i.e. blank) maps get a score of 0 and random maps get an expected score of 0.[2]

In the ideal scenario where all resource types have perfect detection and travel at the same speed, the optimal allocation will follow probability density alone. Therefore *r* is the expected proportion of cells one would have to search before finding the subject, and *R* is the proportional gain over random searching. Because there is a great deal of uncertainty in search, scoring a single case is not very informative. *R* only becomes meaningful when it is calculated for many cases, to compare the average performance of different models on a fixed set of cases at a fixed resolution and extent.

R is sensitive only to rank order, and not to the relative probability. Therefore, the actual values may be converted to a suitable grayscale image using any visually pleasing monotonic transform, and the scoring can be done directly on the image. However, the bit depth of the image will limit the number of possible distinctions: an 8-bit grayscale image has at most 256 possible values, and a 16-bit grayscale image has 65,536.

2.3 Scoring Methodology

We use the format defined for the MapScore website (http://mapscore.sarbayes.org). Each map is a 5,001 × 5,001 grayscale raster centered on the IPP. Each pixel is 5 m, resulting in a 25 × 25 km search area, which exceeds the 95% zone in almost all cases, and represents an upper bound on feasible ground searching. Models need not have 5 m resolution internally, but they must convert their output to the standard format for scoring. MapScore uses 8-bit PNG files, with lighter pixels representing higher probabilities.[3] If the 256 possible values were used equally, then each value would have about 98 K pixels, and *R* would have a maximum value of 0.996.

R can be calculated offline, but using the website creates a public record and encourages comparison with other methods, potentially including subjective estimates. Users may select a case, receive the IPP and case information, and then upload a PNG image file with their probability map for that case. The website then scores the map using the actual find location, which is revealed along with the score. MapScore also allows batch submission via folders or zip files, so long as the individual maps are named to match the cases.

In the next section we discuss three relatively simple statistical models derived from ISRID cases with good initial and find coordinates.

3 Data and Models

Koester (2008) organizes the ISRID cases into 41 categories and subcategories based on scenario, age, medical or mental status, and activity. Critically, he provides 25%, 50%, 75%, and 95% quantiles for the Euclidean distance between the IPP and the find location. Koester also

provides summary statistics for elevation change, hours mobile, survivability, dispersion angle, and distance from nearest linear feature, when available. Where data permit, statistics are subdivided by domain (temperate, dry) and terrain (mountains, flat, and urban). The distance-ring model is the most widely used in WiSAR operations, and linear distance is one of the most reliably-reported features.

Most of the ISRID cases do not contain usable GIS coordinates for both the initial and find locations. However, including the Yosemite data which became available during this study, 376 ISRID cases had reliable IPP and find coordinates. A third of the cases (89) are from New York, where a majority of the state is dominated by farms, forests, rivers, rolling mountains and lakes. It comprises the Northeastern Highlands, Erie Drift Plain, Eastern Great Lakes Lowlands and Atlantic Coastal Pine Barrens ecoregions (Bailey 1995; Bryce et al. 2010). A third were from Arizona (88 cases, transitional between plains and mountains), and a third from Yosemite National Park, California (199 cases), a rugged valley between granite peaks in the Southern Sierra Nevada ecoregion (Bailey 1995).

3.1 Distance Model

The Euclidean distance (ring) model is probably the most common model in statistical search planning. Dating back to Syrotuck (1976/2000), the model draws 25%, 50%, 75% and 95% distance rings based on statistical crow's-flight distance tables (Koester 2008). These distances correspond to the lower quartile, median, upper quartile, and 95th percentile of distance travelled by each category of lost persons in ISRID. As Table 1 shows, Koester's distance model considers terrain and ecoregion where the data permits. Figure 5 shows an example ring model.

Don Ferguson's Integrated Geospatial Tools for Search and Rescue (IGT4SAR Ferguson 2013; https://github.com/dferguso/IGT4SAR) implements all the distance-ring categories and subcategories from Koester (2008) in an ArcGIS toolbox. IGT4SAR extends the MapSAR (http://www.mapsar.net) toolbox to include various elements of search theory. MapSAR is a free and open-source tool that runs with Esri's ArcGIS Desktop 10.X software (http://www.esri.com/landing-pages/software/arcgis/arcgis101-trial) and enables maps to be generated, stored, and printed quickly in order for research teams to be able to perform faster searched for a missing person (MapSAR and Esri 2012).

The IGT4SAR distance model uses the ArcGIS Multiple Ring Buffer tool to create four concentric rings centered on the IPP and representing the 25, 50, 75, and 95% distances for

Table 1 Hiker lost person behavior table used to create the distance rings generated from Koester (2008)

|	Temperate		Dry		
	Mnt	Flat	Mnt	Flat	Urban
n	**568**	**274**	**221**	**58**	**8**
25%	0.7	0.4	1.0	0.8	
50%	1.9	1.1	2.0	1.3	1.6
75%	3.6	2.0	4.0	4.1	
95%	11.3	6.1	11.9	8.1	
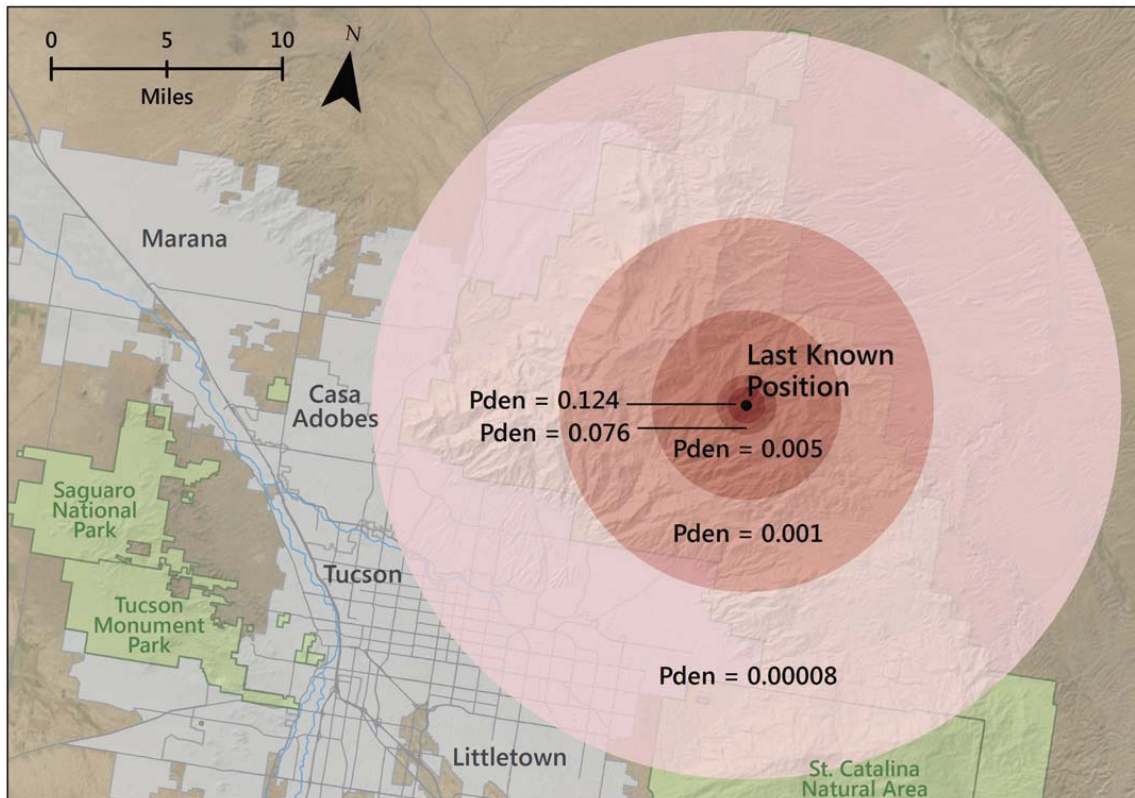
Figure 5   Distance ring model for hikers in flat and dry environments, on a representative basemap. High probability areas are represented with darker colors while decreasing probabilities are shown by light tan color

this subject category and the terrain. The rings are created on a 50×50 km region, and each ring is assigned the appropriate probability. The remaining 5% is assigned to the region outside the 95% circle. The five densities are then calculated by dividing each probability by the area of the corresponding region, and assigned to every pixel in the region. The model then clips the map to the 25×25 km evaluation region.

3.2 Watershed Model

Although the distance-ring model is easy to use on a paper map, it ignores terrain. Terrain plays an important role in WiSAR. About 75% of WiSAR incidents happen in the mountains, and mountains constrain travel. One simple way to account for terrain is to count watershed crossings (Doke 2012). Watershed boundaries follow ridge lines and unlike distance rings, reflect actual barriers to travel. Figure 6 shows an example of the watershed model.

In the US, watersheds are delineated by the US Geological Survey, using a national standard hierarchical system based on surface hydrologic features, and are classified into six units. The six main types of hydrologic units are region, sub-region, accounting unit, cataloging unit, watershed, and sub-watershed. Each hydrologic unit is identified by a unique hydrologic unit code (HUC) and consists of two to 12 digits based on the level of classification. For this article a complete digital hydrologic unit boundary level of the sub-watershed (12 digit) 6th level was used as a base map for the watershed model. The typical size for a 12-digit hydrologic unit is
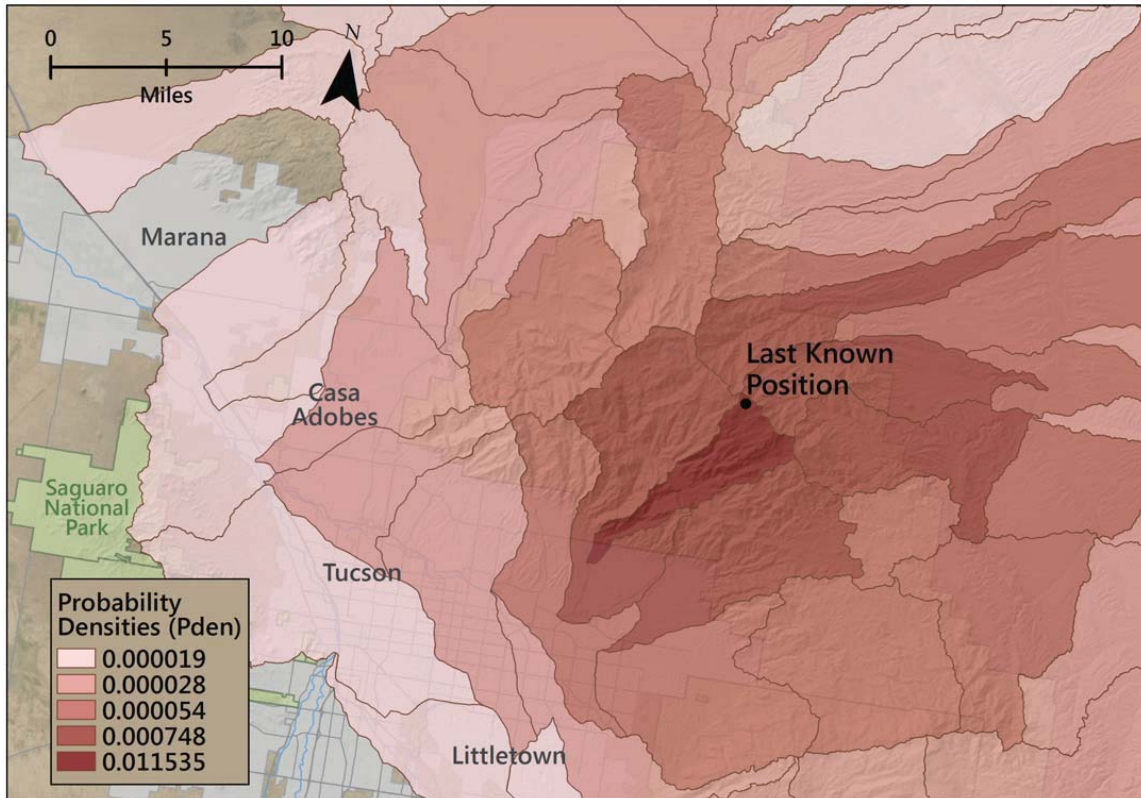
Figure 6 Watershed model showing terrain-based "rings" for a flat and dry environment, on a representative basemap

10,000–40,000 acres; however, in some areas with unique geomorphology the watershed may be greater than 40,000 acres or less than 10,000 acres, but never less than 3,000 acres. The sub-watershed (HUC-12) is the most detailed nationwide layer now available.[4]

The watershed containing the IPP is numbered "0". All the watersheds on its border are numbered "1", so each watershed is assigned a number counting the minimum number of ridges between the IPP and the center of the watershed. We calculated watershed statistics from 398 historical cases, as shown in Table 1. Each incident was classified as either "0", if found in the same catchment as the IPP, "1" if found adjacent, and so forth up to "3". Only 1 in 17 cases (about 6%) were found three or more watersheds away. See Table 2 for details.

Lastly, we divide the watershed-distance probabilities by the areas of all the watersheds at that distance, to get each region's *Pden*.[5]

3.3 Combined DW Model

A combined model may be made by simply "stacking" the two model layers, which is equivalent to a weighted average, or by calculating the actual joint probability distribution on the union of regions. The joint distribution will do better when the two models are not independent and there is enough data reliably to estimate the interaction. A combined model using the joint distribution of watersheds and Euclidean distance was designed with the expectation that the model would do better than the two models taken separately, as is usually the case when combining estimates (Mattson 1980; Surowiecki 2005).

Table 2 Watershed distance statistics gathered using ISRID and Yosemite data

States	0: Same Watershed	1: One shed away	2: Two sheds away	3: Three+ sheds away	Total
Arizona	57	46	7	12	122
New York	71	24	3	4	102
Yosemite	87	74	10	3	174
	215	**144**	**20**	**19**	**398**
Arizona	47%	38%	6%	10%	100%
New York	70%	24%	3%	4%	100%
Yosemite	50%	43%	6%	2%	100%
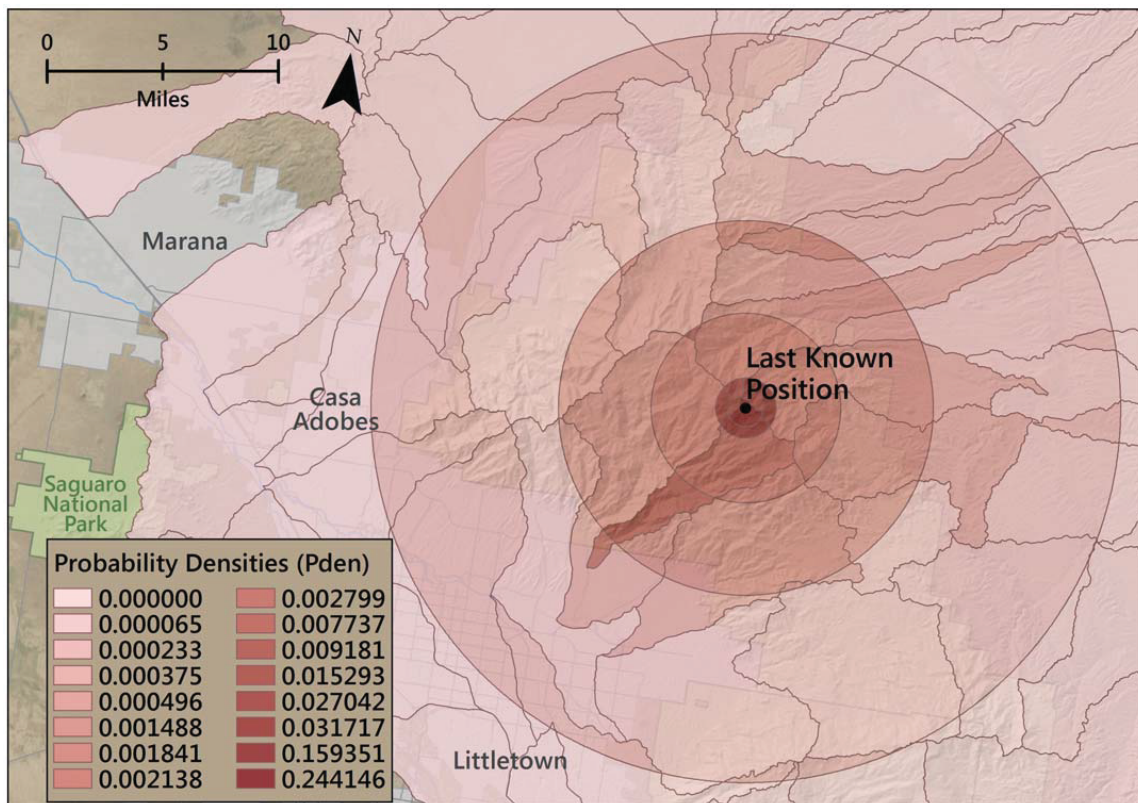
Figure 7 Combined Euclidean and Watershed distance model for hiker in a flat and dry environment. Dark shades represent higher probability density

Figure 7 shows an example of the combined "Distance Watershed" (DW) model. The map regions are created by intersecting the distance rings and the watersheds (using the Union tool) so that a watershed cut by a distance ring becomes two new regions.

The probabilities for the combined DW regions are derived from the counts in Table 3. For example, Table 3 shows that the regions within the same watershed as the IPP and in the 50% ring only contained the lost person in 61 out of 355 cases, or about 17% of the time.

Table 3 Distance Rings and Watershed statistics based on ISRID and Yosemite data

Distance Rings	0: Same Watershed	1: One Watershed away	2: Two Watersheds away	3: Three+ Watersheds away	Total number of cases
25%	93	9	0	0	102
50%	61	25	1	0	87
75%	25	29	1	0	55
95%	17	48	9	4	78
100%	1	7	7	18	33
Total	**197**	**118**	**18**	**22**	**355**
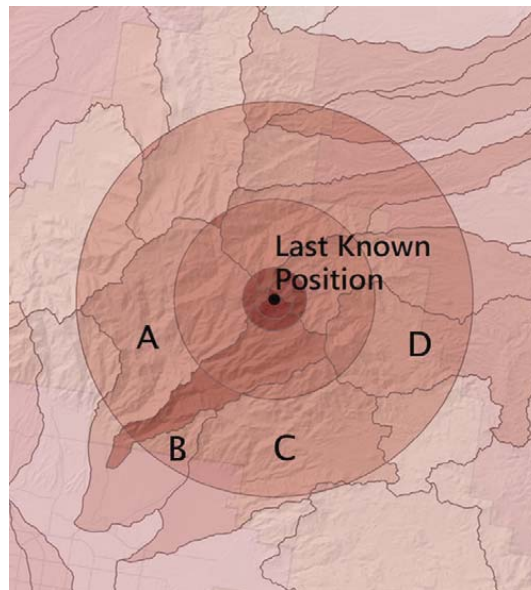
Figure 8 Calculating Pden for the combined Distance-Watershed model

The model then assigns a probability density by dividing the probability from Table 3 by the total area of all the polygons assigned to that DW region in the map. For example, in Figure 8, the regions A, B, C and D constitute the [Watershed 1, 95% ring] region; each is assigned an un-normalized "probability" of 48/355 from Table 3, which is then divided by the combined area A+B+C+D. Note the watershed for region A also extends into the 75, 50, and even 25% rings. Although the probability of the [Watershed 1, 25% ring] region is only 9/355, the smaller area yields a higher *Pden*, shown by the darker shade for the inner two rings of A's watershed.

4 Results

The distance ring model received an average score of approximately 0.780 (95%CI: 0.740 – 0.819). The watershed model received a lower average score of 0.611 (95%CI: 0.572 – 0.650),
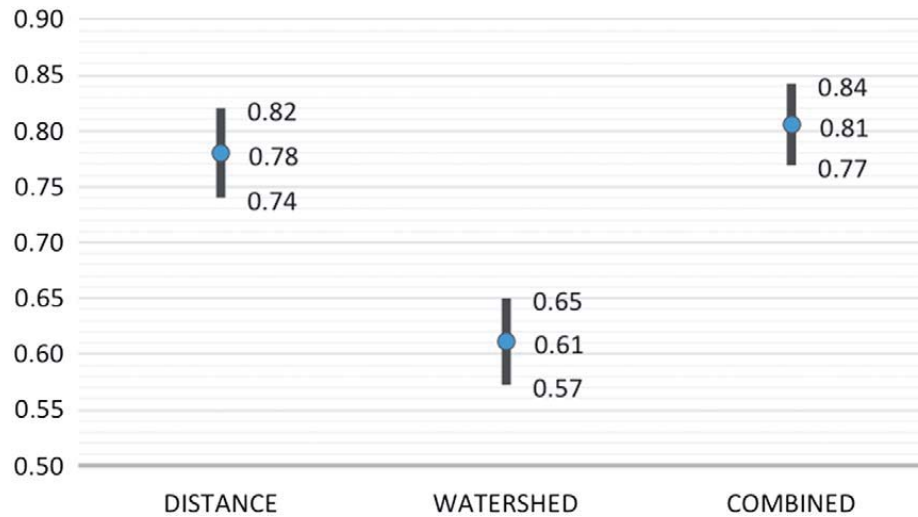
Figure 9   Average rating scores of the three models used in the study. The whiskers represent the 95% confidence intervals of the mean

and the combined model scored the highest with an average score of 0.805 (95%CI: 0.769 – 0.841). The watershed model is clearly inferior to the other two. However, the combined model is slightly better (two-tailed, paired T-test, N = 376, t_{crit} = 1.966, p = 0.017). See Figure 9 for a comparison.

Despite largely ignoring local terrain, the ISRID distance ring model sets a high bar. Beating the ISRID distance model for hikers on our 5,001-pixel-square images requires scoring solidly above about 0.8. By adding some very basic terrain information, the Combined model achieves improvements of about 6% of the original standard deviation, and about 11% of the possible gain.

There was also a regional influence. All models had their best performance in New York and their worst in Arizona where variance was also highest. The difference was statistically significant for both Distance and Combined models but not the Watershed model, which had poor performance in all three regions (F-crit = 3.02, F-value = 11.4, 8.6, 2.8; see Table 4.) Also, performance differences between models were statistically significant in New York and Yosemite, but not in Arizona (one-way ANOVA, F-value = 29.13, F-crit = 3.00). The combined model performed the best and with the least variance for the state of New York, with an average score of 0.887 and variance of 0.059.

5 Discussion

This study had four goals:

- To create a method and portal for scoring missing-person probability maps;
- To score the ubiquitous ISRID Euclidean-distance "ring" model;
- To compare the ring model with a new watershed model; and
- To compare those models with a combined distance-watershed model.

The results for the distance ring model were as expected. Based purely on ring geometry, the expected value of *R* for Hikers in a dry, mountainous domain is 0.78, closely mirroring the actual result (which was indeed mostly hikers in such environments). It was also anticipated

Table 4   Model mean and (variance) by region. F-statistic: α = 0.05, DF = 2, F-critical = 3.020

State	Distance Model	Watershed Model	Combined Model
Arizona	0.632	0.533	0.656
	(0.244)	(0.194)	(0.215)
New York	0.841	0.666	0.887
	(0.129)	(0.122)	(0.059)
Yosemite	0.818	0.621	0.834
	(0.117)	(0.139)	(0.106)
F- statistic	**8.588**	**2.792**	**11.366**
	(p = .0002)	(p = .06)	(p = .00002)

that the distance ring model would score slightly higher in the state of New York than Arizona or Yosemite Park: because development and vegetation limit travel, the distance rings are closer in NY. (The temperate flat category has a 75% of 2 km, vs. 4 km for the dry flat category).

The watershed model did worse than the ISRID distance rings, but performed surprisingly well considering that it ignores the subject category, environment, and climate (unlike the distance-ring model). It also scored higher in New York than in Arizona or Yosemite. The watersheds in our New York cases tend to be larger. Although Arizona has a lot of flat regions, most of the searches happened near the mountains, and the Arizona mountains are more rugged than the New York mountains. Yosemite, of course, is at least as rugged as Arizona.

It also helped that the New York IPPs were more likely to be somewhere in the center of a watershed, rather than on the ridge boundary, making the watershed distance parameter more reliable. When the IPP is on the dividing ridge, it is essentially random which side of the ridge will count as watershed 0.

6 Conclusions and Future Work

The goal of any SAR operation is to increase the probability of success as quickly as possible with the available resources. Search and rescue activities rely heavily upon geospatial data, and GIS generation of the probability maps can speed search planning and generate better plans. However, while higher-resolution models including more factors will always seem more appealing, they need to be tested. MapScore provides a large set of historical missing-person cases, and a web portal for scoring and comparing models.

This article publishes baseline scores for three relatively simple models: the commonly used ISRID Euclidean distance-ring model, a new watershed model which ignores subject category or terrain, and a combination of the two models. The watershed model by itself eliminated about 60% of the search area, but the familiar distance-ring model did better, eliminating over 75% of the search area. The combined DW model eliminated over 80% of the search area, showing a statistical difference. All models did better in New York and Yosemite, and worse in Arizona.

Live GIS-based probability maps should improve key search planning decisions and increase situation awareness. Even if the GIS did not suggest resource assignments, displaying validated scenario-specific probability maps would be faster than drawing regions manually

and more accurate than intuitively sloshing probabilities into those regions. But the models tested here only automate the current manual method.

The next step is to explore parametric distance models[6] to remove the "jumps" in probability at the ring boundaries. Following that, the terrain model should be improved. One option is to refine the watershed layer. The HUC 12-digit watershed layer, although the most detailed currently available, has watershed regions that are too large for search purposes. A finer scale watershed layer may better capture the dynamics of movement and receive better scores. In addition, the watershed model should better account for IPPs on the ridge between the two watersheds, perhaps by assigning ridge cases partially to all neighboring watersheds, or to a separate area.

If there is sufficient data available for the search region, another option is to augment watersheds with other travel barriers like streams and slopes, or skip simple barrier models entirely in favor of calculating travel cost surfaces. Preliminary tests of travel cost models showed the limiting factor was the quality of the available data layers. However, with effort a nationwide set could be synthesized for testing on MapScore.

Finally, these are all but steps along the way to defining actual motion models for SAR. We have not yet tested any motion models, though we are collaborating with other researchers to do so. Motion models have many parameters and assumptions, and without a good test suite like MapScore, they are difficult to evaluate.

MapScore has provided case data, a scoring metric, and a scored baseline. We invite contributions and hope within a year to see models scoring above 0.9.

Notes

1 Syrotuck's model was actually a bit more involved, and his "rings" often resembled paper clips, but most of his readers just used the linear distance.
2 Koester's correction matters in rule-based models where many pixels get the same value.
3 MapScore may switch to 16-bit when participants start submitting higher-resolution models.
4 The Watershed Boundary Dataset (WBD) and the National Hydrography Dataset (NHD) are coordinated efforts between the US Department of Agriculture–Natural Resources Conservation Service (USDA-NRCS 2013), the US Geological Survey (USGS), and the US Environmental Protection Agency (EPA). They were created from a variety of sources from each state and aggregated into a standard national layer for use in strategic planning and accountability (http://nhd.usgs.gov/wbd_data_citation.html).
5 Although this *Pden* method is correct on average, it could generate abnormal *Pdens* if, for example, the watershed-0 region was extraordinarily large (yielding too low a *Pden* near the IPP), or the watershed-3 region was clipped so as to be extraordinarily small (yielding a high *Pden* far away). A better method would be to calculate the average *Pdens* as part of the overall statistics, and apply those directly to each case.
6 Forthcoming. See Cawi (2014) for a preview.

References

Bailey R G 1995 *Description of the Ecoregions of the United States* (Second Revised and Expanded Edition). Washington, DC, US Department of Agriculture, Forest Service Miscellaneous Publication No. 1391
BEA 2012 *Final Report: On the Accident on 1st June 2009 to the Airbus 330-203 Registere F-GZCP Operated by Air France Flight AF 447 Rio de Janeiro-Paris*. Le Bourget, France, Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (available at http://www.bea.aero/en/enquetes/flight.af.447/rapport.final.en.php)
Bryce S A, Griffith G E, Omernik J M, Edinger G, Indrick S, Vargas O, and Carlson D 2010 *Ecoregions of New York* (Color Poster with Map, Descriptive Text, Summary Tables, and Photographs). Reston, VA, US Geological Survey (available at http://www.epa.gov/wed/pages/ecoregions/ny_eco.htm)

Castle T S 1998 Coordinated Inland Area Search and Rescue (SAR) Planning and Execution Tool. Unpublished MS Thesis, California Naval Postgraduate School (available at http://calhoun.nps.edu/public/handle/10945/8156)

Cawi E 2014 The Lognormal Distance Model. *SARBayes*. Accessed October 13. http://sarbayes.org/projects/lost-person-behavior/the-lognormal-distance-model/

Doherty P J, Guo Q, Doke J, and Ferguson D 2014 An analysis of probability of area techniques for missing persons in Yosemite National Park. *Applied Geography* 47: 99–110

Doke J 2012 Analysis of Search Incidents and Lost Person Behavior in Yosemite National Park. Unpublished M.S. Thesis, University of Kansas (available at http://hdl.handle.net/1808/10846)

Ferguson D 2013 WiSAR and GIS Blog: Critical Planning and Analysis Using GIS for WiSAR. WWW document, http://wisarandgis.blogspot.com/2013/09/critical-planning-and-analysis-using.html

Frost J R 1996 *The Theory of Search: A Simplified Explanation*. Annandale, VA, Soza & Co. Ltd. and Office of Search and Rescue, US Coast Guard (available at http://www.navcen.uscg.gov/?pageName=TheoryOfSearch)

Heggie T W and Amundson M E 2009 Dead men walking: Search and rescue in US national parks. *Wilderness and Environmental Medicine* 20: 244–49

Koester R J 2008 *Lost Person Behavior: A Search and Rescue Guide on Where to Look – For Land, Air and Water*. Charlottesville, VA, dbS Productions

Koester R J 2010 International Search and Rescue Incident Database (ISRID). WWW document, http://www.dbs-sar.com/SAR_Research/ISRID.htm

Koopman B O 1980 *Search and Screening: General Principles with Historical Applications*. New York, Pergamon

Kratzke T M, Stone L D, and Frost J R 2010 Search and rescue optimal planning system. In *Proceedings of the Thirteenth Conference on Information Fusion*, Edinburgh, Scotland: 1–8

Lin L and Goodrich M A 2010 A Bayesian approach to modeling lost person behaviors based on terrain features in wilderness search and rescue. *Computational and Mathematical Organization Theory* 3: 300–23

MapSAR and ESRI 2012 MapSAR User's Manual, Version 1.3. Redlands, CA, ESRI Press (available at http://www.mapsar.net/files/mapsar-users-manual.pdf)

Mattson R J 1980 Establishing search priorities. In Haley K B and Stone L D (eds) *Search Theory and Applications*. Berlin, Springer: 93–7

McGrayne S B 2012 *The Theory that Would Not Die: How Bayes' Rule Cracked the Enigma Code, Hunted Down Russian Submarines, and Emerged Triumphant from Two Centuries of Controversy* (Second Edition). New Haven, CT, Yale University Press

Pfau L 2011 Geospatial technology and data for volunteer-based wilderness search and rescue. Unpublished thesis proposal capstone peer review report, Department of Geography, Pennsylvania State University (available at https://gis.e-education.psu.edu/files/Pfau_596A_20110922.pptx)

Richardson H R and Stone L D 2006 Operations analysis during the underwater search for Scorpion. *Naval Research Logistics Quarterly* 18: 141–57

Rossmo D K 1999 *Geographic Profiling* (First Edition). Boca Raton, FL, CRC Press

Sarow E 2011 Determining Probability of Area for Search and Rescue Using Spatial Analysis in ArcGIS 10. Unpublished report

Soylemez E and Usul N 2006 Utility of GIS in search and rescue operations. In *Proceedings of the ESRI International User Group Conference*, San Diego, California

Stone L D 2007 *Theory of Optimal Search* (Second Edition). Reston, VA, Metron Scientific Solutions

Stone L D, Keller C M, Kratzke T M, and Strumpfer J P 2011 Search analysis for the underwater wreckage of Air France Flight 447. In *Proceedings of the Fourteenth International Conference on Information Fusion*. Chicago, Illinois: 1–8

Surowiecki J 2005 *The Wisdom of Crowds*. New York, Anchor

Syrotuck W G 2000 *Analysis of Lost Person Behavior: An Aid to Search Planning*. Mechanicsburg, PA, Barkleigh Productions

Twardy C R 2012 MapScore: A Portal for Scoring Probability Maps. WWW document, http://sarbayes.org/projects/mapscore/mapscore-a-portal-for-scoring-probability-maps/

Twardy C R, Jones N, Goodrich M A, Koester R J, Cawi E, Lin L, and Sava E 2012 MapScore: A Portal for Scoring Probability Maps. Unpublished poster presented at the Military Operations Research Society Symposium, Colorado Springs, Colorado (available at http://sarbayes.org/wp-content/uploads/2012/08/MapScorePoster_MORSS2012.pdf)

USDA-NRCS 2013 *Watershed Boundary Dataset: NY, AZ, Yosemite National Park*. Washington, DC, US Department of Agriculture-Natural Resources Conservation Service, US Geological Survey, and US Environmental Protection Agency (available at http://datagateway.nrcs.usda.gov)

Technical Rescue interface: Search & Rescue and non-Snow/Glacier Mountaineering Rescue

Conover, K., Circh, R. & Koester, R.
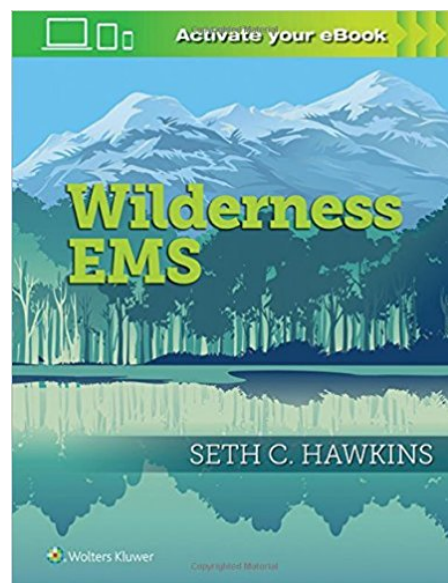
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30 Technical Rescue Interface: Search and Rescue in the Non-Snow/Glacier/Mountaineering Environment

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INTRODUCTION

In this chapter, we provide an overview of wilderness search and rescue (SAR) for those who:

- practice or intend to practice wilderness EMS (WEMS),
- supervise WEMS providers, or
- are interested in WEMS, and are not trained members of a wilderness SAR team.

The chapter focuses primarily on two aspects of wilderness search and rescue that are not covered fully in other chapters. One is search management. The other is the medical aspect of force protection: providing incidental medical care to SAR team members to keep them functioning, and perhaps doing health screening on SAR team members.

It is difficult to know how many SAR operations occur. Information-gathering is spotty at best. The National Park Service keeps reliable statistics, and they show about 3,000 SAR operations per year.[1,2] However, most SAR incidents probably occur outside of national parks: in national forests, in state parks, on other public lands, and on private lands. Some of these are straightforward rescues without much searching, but a significant proportion involves at least some searching.

The standard model of emergency services training these days, at least in the United States, tends to follow a four-level training ladder, likely originating in the regulations and four training levels established for handling hazardous materials by

the U.S. Occupational Health and Safety Administration. The following is an informal interpretation of these levels as applied to other emergency services specialties.

Awareness: you know enough to recognize the hazards, know enough not get yourself killed, and know when to call for expert assistance.

Operations: you know enough to complete simple operations in the specialty, if you are supervised by someone with more experience and training.

Technician: you know enough to complete simple operations without supervision, and to participate in complex operations supervised by someone with more experience and training.

Specialist: you know enough to run even complex operations.

This chapter reviews the awareness level of wilderness search management, participation with search operations in the field, tools to interface with the leaders of SAR teams, and concepts of medical force protection.

TERMINOLOGY: SAR-SPEAK

The English language, as with the Internet, grows without top-level supervision. It's messy. New terms emerge, old terms acquire new meanings, and sometimes terms have multiple meanings. And like any specialty, SAR has its own special terms. Interfacing with SAR teams is easier when you can "talk the talk." It also provides you with some credibility with SAR team members,

though perhaps not so much as when you can "walk the walk" and tell stories about all the difficult rescues you have done. (Some embellishment is expected but it must be done artfully and with at least a modicum of modesty and self-deprecation.)

Search and rescue itself is one of those terms that has come to mean many different things.

Looking for people trapped in a burning building? That's search and rescue.

Looking for live people or dead bodies in collapsed buildings? That's search and rescue.

Looking for and rescuing a downed pilot behind enemy lines? That's search and rescue.

Using SCUBA gear to retrieve bodies from a bus that went off a bridge into the bay? That's search and rescue.

Looking for the wreckage of Malaysia Airlines flight MH370 on the floor of the Indian Ocean using oceanographic sonar? That's search and rescue.

Looking to see if anyone was affected by widespread flooding or a tornado? That's search and rescue.

Looking for a hunter who has activated a Personal Location Beacon (PLB) or a commercial Satellite Emergency Notification Device (SEND)? That's search and rescue.

The difference between "rescue" and "recovery" is critical to understand. In a rescue, the subject is believed to be a patient who will need assistance and potentially medical care. In a recovery, the subject is believed to be a body without chance of survival. Significant risks might be taken to save a life of a patient, but the risk profile of a body recovery operation should be very low.

The *Land Search and Rescue Addendum to the National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual Version 1.0* (which, despite the lengthy and impenetrable title, is well worth reading) provides the following definition of SAR.

Search: An operation using available personnel and facilities to locate persons in distress
Rescue: An operation to retrieve persons in distress, provide for their initial medical or other needs, and deliver them to a place of safety.[3,*]

SAR that best fits the context of WEMS is sometimes called *land search and rescue*. We distinguish land search and rescue from *air search and rescue*, which is (mostly) looking for downed aircraft from the air. The problem with this definition is that ground teams ("land search and rescue teams" in some definitions) form a significant portion of the effort to find downed aircraft, and aircraft are sometimes used to look for lost persons (rather than downed aircraft) on the ground.

We also use the term *land search and rescue* to distinguish it from *maritime search and rescue*: looking for missing vessels (or aircraft) lost at sea.[†]

While the term *land search and rescue* has some currency as the main context where WEMS is done, you can make a good argument that the Coast Guard, which some would argue is a maritime SAR agency, also deals with significant amounts of wilderness SAR. In terms of remoteness, difficult coastal terrain, and length of transport to an emergency department (ED), many Coast Guard rescues fit the bill for WEMS, and some Coast Guard personnel have been trained as wilderness EMT (WEMTs) specifically to deal with such issues.

The term land search and rescue is occasionally used, but we most often talk about *wilderness search and rescue* as the preferred term for the type of SAR that connects most directly to WEMS.

You can argue that U.S. wilderness SAR teams only do a fraction of their work in Congressionally designated wilderness areas, or even state-designated wilderness areas.[‡] On the other hand, a lot of wilderness SAR work is in areas that are at least *relatively* wild, and the term seems to get across the idea better than any other. In addition, as discussed in the Introduction chapter and Chapter 1, the term "wilderness" in the context of medical care is far more expansive than simple governmental designations.

There are three more SAR disciplines that should be distinguished from wilderness SAR.

The term *urban search and rescue* (USAR) has famously come to be synonymous with searching collapsed buildings and trying to rescue people trapped in them. For the most part, this is not really the type of SAR where WEMS should apply; this is usually in urban areas with somewhat-intact EMS and medical systems. In severe or widespread disasters, though, the existing EMS and medical systems may be entirely disrupted, and you can reasonably call it a WEMS context. If wilderness SAR teams respond to support such operations, which is a reasonable and likely highly effective response, wilderness SAR team members should have extra training for the environment and hazards after such a disaster: the hazards are different, at least in some respects, than the environment for which they train and in which they usually respond.

Sometimes wilderness SAR teams help manage lost-person searches in urban and suburban areas. Some such areas contain big parks that are relatively wild, especially at night or in deep winter or after a bad storm that has toppled many trees. Even if it is in a suburban area without such relatively wild area, we tend to call this *urban search* (not USAR which is different). Urban

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[*]http://www.mngeo.state.mn.us/committee/emprep/download/ USNG/2011_1118_Published_Land_SAR_Addendum_1.0.pdf.

[†]The international standards-setting organization American Society of Testing and Materials International (ASTM)'s Committee F-32 on Search and Rescue uses the term land search and rescue extensively; however, this term is not commonly used in the broader search and rescue community.
[‡]For example, New York State has state wilderness areas in the Adirondack and Catskill mountains.

search has its own specific strategies, tactics and hazards, as does a police *missing person investigation*. It is common for wilderness SAR teams with expertise in search management to assist urban or suburban law enforcement with such an urban search. In some areas, such as the San Francisco Bay Area, some SAR teams do more urban search than wilderness SAR. A text and reference on urban search techniques is available.[4]

A more comprehensive glossary of SAR terms and acronyms can be found in the *Land Search and Rescue Addendum* published by the National Search and Rescue Committee. This list is a subset of the more complete glossary found in the *National Search and Rescue Supplement* (NSS). In addition, a more complete discussion of SAR terms can be found from *Selected Inland Search Definitions* which is an appendix within *Sweep Width Estimation for Ground Search and Rescue*.[5]

SAR TEAM CAPABILITIES: SEARCH AND RESCUE

Wilderness SAR in the open desert southwest and in the densely forested wet-cold Appalachians might seem very different, but there are many similarities. Wilderness SAR teams can and do take advantage of mechanical devices such as helicopters, boats, four-wheel drive vehicles and all-terrain vehicles (ATVs). See Chapter 28 for further discussion about mechanical vehicle use in WEMS and wilderness SAR. But the primary transport mechanism for most SAR team members on most operations is the human foot, usually encased in a wool sock (SAR team members mostly, and appropriately, despising cotton socks[*]) and an appropriately sturdy hiking or climbing boot. SAR team members are expected to be able to travel efficiently long distances on foot.[†] The expectations for WEMS personnel may be lower, but SAR team members are generally expected to be able to navigate from point A to point B with flair and élan, regardless of terrain or weather, often using a map, occasionally a compass, but mostly disdaining their GPSs (at least when others can see them). They are expected to be keen-eyed searchers, capable team managers, expert communicators, and survival experts. Misquoting the inscription on the New York Post Office: *Neither snow nor rain nor heat nor gloom of night stays these SAR team members from the swift completion of their appointed tasks.*

Wilderness SAR teams vary widely in their size and capabilities. A few teams are just search teams… they find lost people, but do not provide any first aid, medical care or rescue. Mostly these are teams that field air-scenting or trailing dogs, though most teams that have such dogs also provide at least first-aid-level care and do some rescue. Some teams provide a full range of SAR services, including technical cave and mountain rescue. Some states offer certification of team by certain minimum requirements, which provides some assurance of quality. Sometimes this certification is by a state agency, sometimes it is by a statewide association of SAR teams. In North America, the generally accepted highest level of wilderness SAR team competence is that provided by the Mountain Rescue Association (MRA).

SEARCH RESOURCES, STRATEGY, AND TACTICS

SAR *resources* (things, people, or animals that can search: planes, trains,[‡] and automobiles, as well as horses, dogs, humans, helicopters, drones, and the like) can use different *strategies*. A strategy can be carried out using different *tactics*, depending upon the task's specific requirements. The strategy of *confinement* ensures that the subject does not leave the search area unbeknownst (it has happened). *Attraction* is a strategy for mobile responsive subjects who will move toward a noise or light source. *Investigation* collects additional information or sightings about the missing subject. *Hasty searches* follow well-defined linear features, a known route, or go to specific spots where the subject might be located. *Area searches* cover larger areas with either multiple resources or a single resource following a well-defined search pattern.

Most SAR tasks are designated to use one of these strategies, using resources such as human ground searchers, dogs, mounted teams, ATVs, snowmobiles, or mountain bikes. Man-trackers and tracking/trailing dogs try to follow the subject by visible tracks or scent. Man-trackers sometimes learn the subject's direction of travel, or document clues, or do *cutting for sign* (described later). Aeronautical resources (low-flying light aircraft, helicopters, or drones) can cover an area using different search patterns. They can do a hasty search by following a known route, search specific linear features or likely crash sites (such as where the flight path crosses a mountain range), or use electronic equipment to search for radio or radio-beacon signals.

Humans

There are various human being search *tactics*: techniques for looking (or sniffing) for a lost person, or looking for clues to the lost person's whereabouts. Some textbooks classify human search tactics as *Type I* (emphasizes speed more than thoroughness),

[*]Unlike wool, cotton retains water against the foot, making the foot colder in cold environments, also keeping the foot damp and making blisters more likely. Cotton under the sole of your foot mats down and becomes hard, but wool socks retain their cushioning effect on the sole.
[†]Experienced members who serve in the field also quickly learn to appreciate the particular competencies of those who stay at base and keep the operation running. And there are those who, in this increasingly Internet-connected world, stay at home in their pajamas and help with *remote support*, which is discussed later.

[‡]Although trains are not usually considered search resources, some wild areas are traversed only by train tracks, so interviewing the crew of trains passing through might be helpful.

Type II (a balance of speed and thoroughness), and *Type III* (emphasizes thoroughness more than speed). Most SAR people, though, rely on the roughly equivalent terms *hasty*, *sweep*, and *line* (or *saturation*) for tasks.

Early in a search, especially when searching for a likely responsive subject, it makes sense to use available resources for less-thorough but more widespread searching, using hasty and sweep tasks. With a wide-spaced sweep task, searchers may be spaced far beyond their visual sweep width for detecting an unresponsive subject and certainly for small clues. However, they likely have much larger and overlapping sweep widths for *hearing* a responsive subject.

In the past, it was taught that repeated non-thorough (eg, sweep) tasks were more effective than a single line/saturation task with the same amount of searchers and searcher effort. This was based on a mathematical model that has since been shown to be incorrect.[6]

For an aircraft searching a segment, it therefore is best to do a single pass over the segment with *close* track spacing instead of multiple passes over the segment with *wide* track spacing. Applying this finding to ground search is a bit trickier, however. Close-spaced human-searcher saturation or line search tasks are usually done by large teams that have high *operational friction*. Operational friction consists of those things that suck up time and effort, or otherwise impede operations, but do not contribute directly to the search effort.

Convoys move at the same speed as the slowest vehicle, and the more vehicles in a convoy, the more likely you will have a slow vehicle. If a vehicle needs to stop for gas or some other reason, the entire convoy needs to stop, and the more vehicles in a convoy, the more likely a vehicle will need to stop. Even in this day of ubiquitous GPS apps on smartphones, dividing up a convoy still seems to cause major complications and is best avoided.

Hiking groups move at the same speed as the slowest hiker, and the more hikers in a group, the more likely you will have a slow hiker. If a hiker needs to stop to retie a boot, the entire group must stop, as breaking up a hiking group is even worse than breaking up a convoy. And since saturation/line search teams are basically large synchronized-hiking groups, this applies to them as well. Large saturation/line search tasks have other sources of operational friction, such as parts of the line drifting downhill, so that the leader must call a halt and move searchers back and forth to re-dress the line.

The higher operational friction of line searches might mean that, unlike aircraft searches, repeated sweep searches actually *might* be a more effective use of searchers compared with a line search. Until someone does a comparative study, carefully *not* controlling for operational friction, we won't know for sure. Even if most search managers don't believe that repeated sweep searches are better than a line search, sometimes a repeated sweep is appropriate. If a segment has already been searched by a sweep search, but a new clue makes it much more likely that the subject is in that segment, it may be appropriate to get another sweep task into that area quickly, as a sweep task is usually quicker to dispatch into the field than a line search task.

Trailing and *air-scenting* are tactics which work best if you have a long nose, pointy ears and four feet, and we will discuss search dogs in the next section. If you're a dog, you may consider the human sense of smell laughable. But there are searches where the smell of fire or aviation fuel led human searchers to a small-aircraft crash site, which leads to advice to human searchers to *use as many senses as you can to search* for clues: *vision* (including checking out suspicious clumps of brush, and from time to time turning around and looking with a different view, and even looking up in trees), *hearing* ("JAKE, CAN YOU HEAR ME?! JAKE?!" [then stop and listen intently]), and *smell*.

A hasty search task is often sent to search along a linear feature such as a trail or a stream. Another type of search, used either after hasty search tasks or sometimes at the same time, is searching an assigned *area* rather than a linear feature. This can be with an air-scenting dog, zig-zagging through the area. It can also be with a team of humans in a line traversing the area, sometimes called *area search*. When the humans are very widely spaced, we call this a *sweep search*; when close-spaced, we call this *line search* or *saturation search*. Sometimes hasty search and sweep search are combined; a linear feature can be searched with flankers out to either side of the linear feature looking for clues as well as a responsive subject, though this slows down the team and may delay them in finding a responsive subject along the trail.

Search resources (field teams) vary in their ability to find clues. An air-scenting dog and handler can rapidly search an area and find, or exclude the possibility of finding, a human being in that area. A sweep task with human searchers, though slower, is much more likely to find clues, such as tracks that can be identified as the subject's, or something left by the subject.

One of the authors once found what are arguably the two best clues of which we have heard, both on the same task, off the Appalachian Trail in a ravine in Virginia's Blue Ridge Mountains. First, a plastic bag of clothes with the subject's name on tapes sewn into each item. Second, after man-tracking from that point (see below) and calling out the subject's name, a response of "I'm over here, dammit!"

Man-tracking (usually just shortened to *tracking*) is a technique that has long been used in law enforcement. It probably started by using guides skilled at tracking wild game applying their skills to track humans. Man-tracking was introduced to SAR teams in the 1970s by those such as the late Ab Taylor of the U.S. Border Patrol. The Border Patrol uses man-tracking to locate illegal immigrants, but Ab also put his skills to work to find lost children, and brought these skills to the attention of SAR teams, developing a cadre of SAR tracking instructors.

Teaching searchers how to search for, identify, protect, and follow human tracks is now part of the training of most wilderness

SAR teams. Trained searchers are expected to be *clue-conscious:* to know how to identify human tracks and appreciate their value as clues, especially in untracked wild areas, and to protect them. One of the authors, searching such an untracked area, found a track crossing perpendicular to his assigned hasty task, going from north to south. This directed the search strategy to the area south of his assigned search task, where another team quickly found the lost subject, a 92-year-old woman who had been mushroom-hunting and had fallen and gotten her leg trapped between two rocks. She had been stranded there for days, but luckily was right next to a small stream with water. This points out how a single track can serve as a clue and result in a save.

Searchers are sometimes tasked to *cut for sign* (also known as *sign-cutting*). This means to search, either in circles around a clue, or perhaps perpendicular to the subject's projected line of travel, looking for tracks ("sign").

Some SAR team members go on to advanced training in man-tracking, and may be dispatched to a potential track to start tracking at that point, using the step-by-step method taught by Ab Taylor and others. Man-trackers may start at the *Point Last Seen* (PLS), or if a good clue establishes it, the *Last Known Position* (LKP), but often investigators have trampled the tracks there. Scent-specific trailing-dog tasks are sometimes used from the PLS instead, though with frustratingly low rates of success.

Dogs

Many animals have highly refined senses of smell, and could theoretically be used for searching—in particular, pigs and buzzards seem to feature frequently in SAR humor—and horses used by mounted teams have a keen sense of smell compared to humans, which adds to their baseline usefulness as mounts for humans. But the animal most used for lost-person search is "man's best friend," the dog. There are arguments about which breed of dog is best for SAR, but this is best left for informal discussion (probably both lengthy and heated) with a group of knowledgeable dog handlers, as there is no consensus even as to whether one breed is best, much less which breed. Search dogs can be highly effective at finding those lost in a wild area.

As with the term *search and rescue*, the term *dog team* can be more than a bit confusing when used in conversation, and we know of four separate meanings of the term. On the one paw, a *dog team* can be a wilderness search organization, all of whom are dog handlers. On the other paw, a *dog team* can also be a search organization, only some of who are dog handlers, although this more commonly is called a *wilderness SAR team with dogs*. On the third paw, a *dog team* can be a team sent out on a search task, consisting of a handler and dog working together, along with one or a few other humans who are called *walkers* or *flankers:* SAR team members who accompany the handler stay well back and often handle communications and some

navigation. The usual term for such a group heading out for a search or rescue is *field team*. But the teams that are specifically tasked to use a dog, usually for an air-scenting or trailing task, are sometimes informally called a *dog team* to distinguish them from the other, non-dog teams, which are called just *field teams*.

On the fourth and final paw, we have a *dog team* of one human handler and one dog who have trained together, tested together, and have been credentialed as competent in a specialty such as air-scenting, trailing, or human remains detection (HRD). It takes lots of time and dedication, on the part of both the dog and the handler, to become a competent and credentialed dog team. There are quite a variety of credentialing agencies for such search dog teams, with different testing standards; if you ask a dog handler about them, you will probably get a strong response about which are of high quality and which are not. But, as a dog handler in the Appalachian Search and Rescue Conference (ASRC) once famously observed: "If you get three dog handlers together, about the only thing you'll get two of them to agree on is that the third one is wrong."

Dogs have different training and capabilities. There are a variety of dog specialties, including water search (searching from a boat), cadaver/human remains detection (HRD), collapsed-structure search, avalanche search, and evidence search. The two most commonly used in wilderness SAR are *air-scenting* and *trailing*.

First, let us describe how to do an air-scenting task. To make it easier to appreciate, we will describe this from the dog's view.

Your human handler and the other humans will usually follow a trail, a stream, or perhaps steer a fairly straight course through the middle of an assigned search area (SAR teams often call this a *segment*). You should stay ahead of the humans; stay close enough that you can hear them, but being out of sight is OK, at least for brief periods. While they are struggling along behind you (humans can be quite slow in the woods), you should run back and forth ahead of them, sniffing carefully for the distinctive scent of a human, any human. As any competent dog knows, individual animals (including humans) all have a slightly different scent, but animals have a distinctive species-specific smell. It is said that foxes are particularly sharp and acidic, whereas humans are warm and complex with overtones of oak and cedar, especially if the human has been eating beef, and often a yeasty finish if the human has been eating bread or drinking beer, but perhaps this is just one dog's interpretation. This scent is created by small bits of skin, hair, and evaporating skin oils that animals give off. This material floats downwind, spreading as it goes, in a *cone of scent*. When you are air-scenting, keep your nose up and sniff periodically. Ignore the scent of the humans with you, but keep sniffing for a different human.

When you are air-scenting, you are just sniffing for an unexpected human scent, any unexpected human scent. As soon as you scent any human other than your team, check the wind direction and remember it. When training your human, you

should have worked out a standard way to communicate this "alert"; whatever it is, run back to your human (for some reason, an alert *never* happens when you are right next to your handler) and give your alert signal, whatever it is. Once you are sure your human has paid attention and acknowledged your alert, it's time to head out and try to catch that scent again. Winds shift, so you will usually have to range back and forth until you can smell it again. And sometimes, you won't find it again; c'est la vie. Still, even a single alert can be useful to those back at Base who are plotting these things on a map. If you are lucky, you will get another noseful of that same scent, at which time your job is to follow that scent upwind until you find the search subject. If the wind shifts, you may need to range back and forth a bit more to pick it up. It is important to remember that old search-dog mantra: *humans are slow*. While there is a certain competitive urge to get to the subject as fast as possible, you may need to slow down a bit so your humans don't get out of barking range.

When you find a search subject, you need to communicate this with your handler who, as usual, is probably lagging far behind. Run back to your handler, give the signal that you have taught your handler, get a response that you have been understood ("Show me!" seems to be pretty standard) and then lead your handler back to the subject. This is called a *refind*.

With air-scenting, there is lots of scent in the air, at least when you get close. But for *trailing*, you have got your nose down near the ground, trying to find some of that scent that has drifted down onto the ground. That makes it harder, as there is less scent, and the older the trail the less scent is left; sometimes they have you try to follow trails that are a couple of days old, which is well-nigh impossible. What is worse is that you have to pick out the right person's trail from other people's scent trails; unlike air-scenting, trailing is *scent-specific*. If you are lucky, your handler will have a good scent article in a paper or plastic bag for you to check from time to time. Ideally this is from someone who has been trained how to collect a good scent article without contaminating it, but you will have to work with whatever you have got.

As discussed above, *man-tracking* is a well-trained human visually following someone's footprints or other signs of passage; do not confuse it with a dog's *trailing*.[*]

Containment

When searching for a lost person in a wilderness area, searching may be complicated by the fact that the subject may still be moving, resulting in an ever-expanding search area. Thus, we arrive at the key concept of *containment:* knowing if the subject leaves the established search area.

There are many tactics that can help contain the search area. You could:

- Post notes at trail intersections "this way out."
- Run string lines with flagging tape on them, and small signs saying "this way out."
- Put camp-ins (a couple of searchers camping out) at locations where a lost person might reasonably end up, such as a major trail junction, or the main approach to a mountain climb. A camp-in team may carry in a tent, sleeping bag, sleeping pads, a stove and food, and may serve as a rest and resupply area for more mobile field teams.
- Create a "track trap" in an area where a mobile subject might travel: sweep an area of mud, dirt or dust flat, so it is ready to accept good tracks, and then send teams to check the track trap on a regular basis.
- Have searchers do slow patrols along roads around the area from a vehicle. Have searchers similarly walk to patrol trails that bound the area. These tasks may be particularly useful to get less-trained and less-fit searchers into the search effort.

However, patrolling or searching by vehicle is not nearly as sensitive for either clues or subjects as foot-based searchers. Once upon a time, in a large wilderness area traversed by the Appalachian Trail in southwestern Virginia, both foot searchers and trail-bike motorcycles looked for the subject for many days. When finally found by the foot searchers after almost a week, the subject commented, "the only time I was afraid for my life was once when I almost got run over by a motorcycle."

SEARCH THEORY AND STRATEGY

For many years, researchers have worked to get search management into a more scientific framework. This has resulted in a fair amount of literature, and several computer programs designed to assist search managers. Here we will review only the most prominent aspects. If you are interested in more details you can consult the literature on this topic.[5,7–9] In particular, a rigorous but very readable introduction to search theory, prepared for the U.S. Coast Guard by J.R. Frost, is available free online.[10,†]

The central equation of search theory is:

$$POS = POD \times POA$$

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[*]Some dogs are trained to sniff individual tracks to follow a subject, and this is sometimes called canine *tracking*, but trailing is a more common method for dogs to follow a subject.

[†]http://www.navcen.uscg.gov/pdf/theory_of_search.pdf; note that this paper uses probability of containment (POC) for what is more commonly called probability of area (POA); POA is the terminology adopted in this chapter. Note also that in this document equations 2.4 and 2.91 are missing some minus signs; equation 2.4 should read "$POC_{after} = POC_{before} \times (1 - POD)$ and equation 2.91 should read $POD_c = 1 - (1 - 0.6)(1 - 0.7) = -0.88$.

POA is *Probability of Area:* the probability* that the subject is in that circumscribed area. **POD** is *Probability of Detection:* how likely the search technique will find the subject if the subject indeed is in that area. Multiply the two, and you get the **POS** or *Probability of Success:* the probability that you will find the missing subject.

With this equation, we try to quantify, and then combine, two uncertainties. The first uncertainty is probability that the subject *is in* a particular search area segment (Probability of Area = POA). The second uncertainty is the probability that your search tactic *will find* the subject *if* the subject is in the area searched (Probability of Detection = POD).

If you are 100% certain the subject is in the area (POA = 100%), and you search it with a tactic that never misses a subject (100% POD), then you have 100% × 100% = 100% chance that you will find the subject (100% POS). Note that the math is easier if you do it using probability rather than percentage. A probability of 100% is the same as a probability of 1.0; in this case, $1.0 \times 1.0 = 1.0$.

If you are 50% certain (probability 0.5) that the subject is in the area (50% Probability of Area), and search it with a tactic with a 50% Probability of Detection (probability 0.5), then multiplying them together ($0.5 \times 0.5 = 0.25$) gets you a 25% Probability of Success.

The goal of search theory is to find the subject in the shortest amount of time. The most powerful SAR tactical decision aids calculate the *probability of success rate (PSR)*, which is a measure of how effectively you are using your available resources to find the subject. The aid then tells you how to allocate your resources appropriately to maximize it.[3]

Defining the Search Area

The first step in planning the search is to plot an *Initial Planning Point* (IPP), using either the PLS (point last seen, where the subject was last seen by a human observer) or the LKP (last known position, a position established by a reliable clue). The next step is to define the overall search area: What will I search, and where will I send some (or no) resources? Too small an area, and you may miss the subject. Too large, and you may never be able to finish searching the area with your available resources. Textbooks traditionally describe establishing the search area through a four-step process of Theoretical, Statistical, Subjective, and Deductive.[11] Actual practice tends to involve your looking up the 95% distance the subject is likely to travel from the IPP, based upon statistical models.[12] Then, you reduce the search area where there are obvious travel barriers (eg, an impassible river). Finally, you match the boundary of the search area to features a field team could find on the ground.

We mentioned containment above, but there are many times when containment is not a major factor for search planning. When a person has been missing for several days, the possible travel distance makes the potential search area huge, usually orders of magnitude larger than could be covered by available resources. In such cases, the actual search area is much smaller than this theoretical area.

To aid us in deciding how large an area to search, and which areas within that we should search first, we can use data on lost person behavior. Robert Koester, a long-time search manager of the ASRC and one of this chapter's authors, also authored a book called *Lost Person Behavior* that provides this information, which is also available in a smartphone app.[12] For example, if you are searching for a lost hiker, you can consult *Lost Person Behavior*, which recommends concentrating on trails, *cutting for sign* around decision points: points where the trail route is unclear and a hiker might go astray. Cutting for sign means traveling carefully around the decision point, searching intently for human tracks. If we look at the statistics in *Lost Person Behavior*, we find that 50% of hikers are found within 1.9 miles (3 km) of the IPP, and 52% were found downhill from the IPP. Thus, even if the subject cannot be contained, search efforts can be focused on the most probable areas.

Probability of Area

Search theory rests on the premise that, while the location of the subject is unknown, some areas are more likely to contain the subject than others. Much like looking for your lost keys, they are more likely to be in some specific locations than others (coat pockets?) The actual probability for each area ranges from near zero to approaching one. You can use three main methods to determine the initial POA.

For decades, the traditional land SAR method has been the *Mattson consensus method*.[13] This is based on information from your investigations, and is a consensus of subject matter experts you gather together, calculated mathematically. The Mattson consensus may also include information from the other two methods.

The second method is a *statistical method*, also known as the *stochastic approach*. It takes various models (or a single statistical model) of where people (or aircraft, or ships) tend to be found, typically calculated from an IPP. Figures 30.10 to 30.14 provide examples of this approach. Wherever the subject was last seen by a human (seeing them on live video or on a time-stamped video recording counts) is the PLS. Wherever the subject can last be **located** (for example, by a good clue) is the LKP. The point first chosen as the starting point of the search, whether it is the PLS or an LKP, is the IPP. Segments of the search area are then assigned POA. This is the model most commonly used to look for missing aircraft based upon track information.

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*Purists insist we call this *conditional probability* but *probability* is good enough for everyday use.

As mentioned above, one of the authors once found, deep in a ravine, a plastic bag of clothes with the subject's name on name tapes sewed into each. The PLS was back, up on a ridge along the Appalachian Trail. This clue reliably established a new LKP, and it refocused search efforts.

The final model is a *particle motion* or *Markov model*. This is the model used by the U.S. Coast Guard; it considers how the subject may move due to wind and currents in the ocean.[14] A particle motion model creates a mathematical set of rules defining how a particle moves, and essentially rolls the dice (introduces probability) for each discrete move. You then run a Monte Carlo simulation on hundreds or thousands of particles. Then, using specified time parameters, where the particles end up define the probable locations. This particle motion technique is seldom used to predict the location of missing people on land.

Some computer programs allow you to combine these techniques to calculate one composite POA for each of your search area planning regions or segments.

Segmenting the Search Area

When planning area searches (air-scenting, sweep or line/saturation tasks), search managers generally *segment* (using the word segment as a verb) the area into small, searchable *segments* (using the word segment now as a noun). A rule of thumb—actually the rule of *two* thumbs—says that on a standard-scale USGS topographic map, the area covered by your two thumbprints is about the right size for an air-scenting dog or human search task. A field team can usually search such a segment in 4 to 6 hours, and can usually complete two tasks in a 12-hour shift. Linear features may also be assigned a segment number for purposes of planning hasty search tasks. Some method is then used to assign a POA to each segment, and you generally send teams into the segments those with the highest POA first. Segmentation is an art taught to SAR managers; the segments must not only be of a reasonably searchable size, but must have boundaries that can be well seen on both the map and in the field (**Figure 30.1**).

More terminology: *search area* generally refers to the entire area currently being searched, and searchable *segment* (using the word again as a noun) usually refers to a small portion of the search area, assigned to a particular *field team* to search during a *search task*. Sometimes people to refer to a small segment as a search area; refer to the context to figure out the usage.

There is one "segment," or better, *region* that is not on the map, and is referred to by the acronym ROW (*Rest of World*). Searching particularly high-probability locations in the ROW, particularly nearby bars, is a part of some searches and has given rise to the common term *bastard search*, though a much more politically correct term, especially if you are dealing with a subject with dementia, is *investigative search*.

The Mattson Consensus

The original method for assigning land search POA is the *Mattson Consensus Method*, named after the U.S. Air Force's Robert J. Mattson, who taught this method at the joint U.S. Air Force—U.S. Coast Guard National Search and Rescue School in the 1970s.[13]

The original, basic, pencil-and-paper method works as follows. First, choose a small number of people who have some sort of qualifications to provide an educated guess as to where the subject might be. (The guesses of psychics are usually classed as "uneducated" and not included.) Things that might lead to an educated guess include:

- specific knowledge about the search subject;
- experience at running searches;
- knowledge of the local terrain, including such things as popular hiking trails, good fishing streams, or favorite hunting areas;
- thorough knowledge of lost person behavior; or perhaps
- training in using Geographic Information System (GIS) to, for example, predict travel times on and off trails.

Next, divide the search area, not into searchable segments, but into *planning regions*, and assign each region a letter. These regions may be larger (or smaller) than searchable segments, as they are for assigning POA, not for creating specific tasks.

Then, using a pencil and paper (see **Figure 30.2**), make a list of the search region letters down the left side of the paper, then a draw a grid next to this. The grid needs a horizontal row for each planning region, plus an extra one for ROW.* It also needs a vertical column for each of the people who will be contributing their thoughts; you can call them your *Mattsoners*. Add another column at the far right for the averages.

Have each Mattsoner assign a POA to each region, including the ROW "region." For a traditional Mattson, each Mattsoner must be capable of some mental math: the total POA for all regions, including the ROW, must add up to 100%. (This is why computer programs are so popular for doing this.) Mattson recommended that all the Mattsoners use a separate sheet of paper, and list their percentages privately. This avoids peer-pressure effects that might dilute the wisdom of this particular crowd. Then, have someone enter the values in the grid illustrated in **Figure 30.2** and do the calculations.

Finally, it is a simple matter (at least if you are a computer) to average all the readings. You use the averaged POA for each of the regions to direct your search strategy: search the regions with the highest POA first. Given the results of the Mattson Consensus in Figure 30.2, and the reality that at the time of this consensus there were just three field teams currently available, those teams should be assigned to Regions A, B, and C. If the

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*Some question whether we really need to include the ROW, but it is traditional.

FIGURE 30.1. Segmenting a Search Area. Initial segments for a man who ". . .went up the holler to do a bit a huntin' on Calf Mountain." Illustration by Keith Conover, MD, FACEP. Used with permission.

first set of planning regions corresponds with the segments on the map in Figure 30.1, A=1, B=2, C=3 and so forth, then send teams to segments 1, 2 and 3.

There are issues with the classical Mattson method. Mattsoners will sometimes give you a set of probabilities that add up, not to 100%, but to 90% or 120%. Scaling these entries so they *do* total to 100% is sometimes called "coherentizing" the entries. Or, Mattsoners assign probabilities for a few of the more likely segments, then simply provide a similar low probability for all the rest (cheating).

These are indicators of the *cognitive friction* of the process. Think of cognitive friction as things that make a computer application "*not* user-friendly." Cognitive friction is a term coined by computer user-interaction guru Alan Cooper in his book *The Inmates Are Running the Asylum*.[15] He defines cognitive friction as ". . .the resistance encountered by human intellect when it engages with a complex system of rules that change as the problem permutes." Charles Twardy, in an online blog post about the Mattson process, says "People are often incoherent: their probabilities don't add to 100%. We get an 18% gain in accuracy if we coherentize their estimates. But we get a much bigger *30% gain* in accuracy if we also assign more weight to coherent estimates."[16] In simple terms, we rate the advice of people whose estimates add up to 100% over those whose don't. He references a paper he coauthored to support this.[17]

FIGURE 30.2. Mattson Consensus. The numbers along the left, and the rows, refer to segments of the search area. The columns have been filled out by participants in the Mattson Consensus; their names appear at the top. The numbers represent their educated guess as to the POA (Probability of Area: the probability the subject is in the area). The far-right column averages the percentage entered by the participants and is used to assign task priority. Illustration by Keith Conover, MD, FACEP. Used with permission.

Twardy goes on to say "Our 'decision aids' might be hiding carelessness, incapacity, or neglect which we would do better to recognize and ignore."

Or, perhaps we do not need to invoke carelessness or neglect. This may simply indicate that people who can overcome the (high) cognitive friction of the classic Mattson system provide better estimates, and by providing a system with lower cognitive friction we can overcome this.

Twardy notes that Mattson variants with a lower cognitive friction tend to coherentize the POA estimates. He cites two of these:

- **Proportional**: allow people to put in whatever percentages they want, and don't worry about them totaling 100%. Scale them (usually using a computer) so that they now *do* total 100%.
- **O'Connor**: instead of percentages, Mattsoners enter probabilities as follows, then they are scaled to percentages adding up to 100%:

A - very likely in this segment
B
C - likely in this segment
D
E - even chance
F
G - unlikely in this segment
H
I - very unlikely in this segment

These two methods require a computer, or at least a calculator. But smartphones are ubiquitous now, and not only are there smartphone calculators, there are also smartphone spreadsheets, so it is hard to argue that the technology to carry out these calculations is not readily available. And given these methods are easier to perform and less likely to result in error, it is hard to argue for the traditional Mattson. With the Proportional method, it is common to ignore the ROW "planning region"; you do not search it with searchers, you search
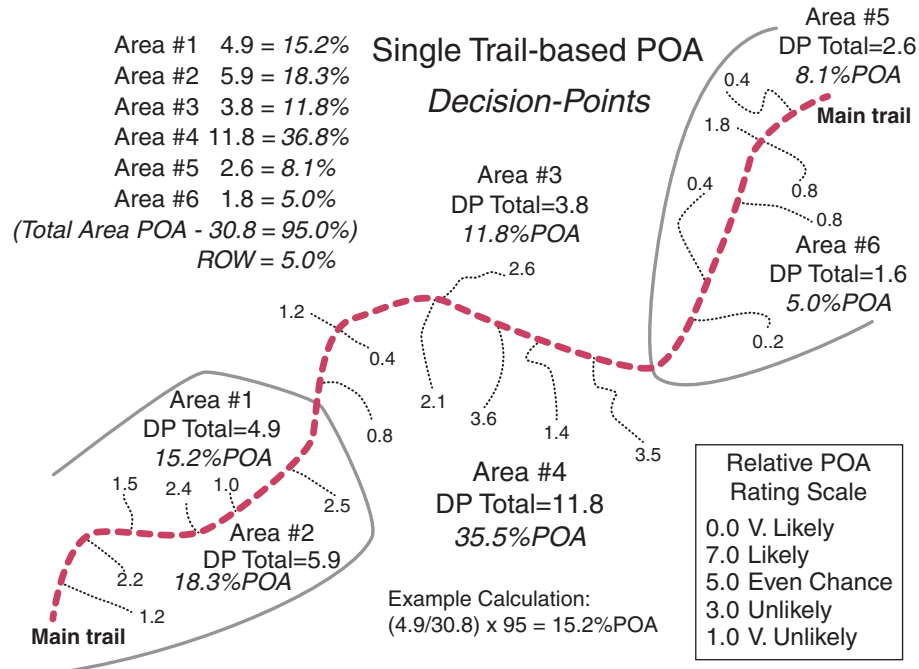
FIGURE 30.3. Trail-based POA. For each decision point along the trail, the field team estimates a probability, from 1 to 8, of how likely it is that the subject would have left the trail at that point. The areas off either side of the trail are segmented into six search areas (segments). By using the number of decision points leading into an area, and the relative probability that the subject would leave the trail at each decision point, a trail-based probability of area (POA) can be estimated for each area. Illustration by Martin Colwell. Used with permission.

it by investigation. The Proportional variant is recommended in the literature.[6]

Trail-Based Probability of Area

Trail-Based POA methods determine POA by non-Mattson methods. There are two meanings of the term Trail-Based POA.

First, in the early phases of a search, it is common to send hasty teams along trails or streams looking for a responsive subject, saving sweep searches of areas for later efforts. It is possible to assign each trail a POA via a Mattson Consensus or some similar process. We should probably call this *Probability of Trail* or *Probability of Stream* or perhaps *Probability of Linear Feature*.

Second, and a much more common usage, has been popularized by the writings and teaching of Martin Colwell, of Lion's Bay Search and Rescue in British Columbia. The key to this is looking for *decision points* along a trail and assigning each a probability that the subject might have left the trail at each (see **Figure 30.3**). This allows you to determine a POA for areas to either side of the trail. Examples of decision points include:

- misleading dead-end side trails,
- overshoots off trail switchbacks,
- minor trails that intersect the main trail,
- apparently easy shortcuts,
- enticing "natural routes" that follow easier ground,
- overused and "braided" trails,
- visible or marked attractions off the main trail, such as springs, shelters, or viewpoints, and
- "one-way" decision points, where the route forward leads onto a more-used trail or dirt road, but the route back involves finding a nonobvious trail turning off from a well-worn trail or dirt road.[18]

For popular trails, you may know these decision points ahead of time. If you are on a field team doing a hasty search along a less well-known trail, you can keep an eye out for decision points. Whenever you find one, you can perform a quick consensus of all team members to establish how likely the subject might have left the trail at the decision point. Based on the number and probability of each decision point leading off a trail into a search segment, Base can use this to calculate a POA for that search segment. Martin Colwell has written this up in a detailed paper available online.[19]

Statistical Method

Another alternative to a Mattson-style consensus is to use statistical data to determine the most likely search segments; statistical data can also be shared with Mattsoners before performing a consensus. If the subject is lost in an area where people get lost all the time, you might look first in the segments where you have found lost people before. If not, you can use aggregated lost-person

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behavior from many searches. Gather data from your Missing Person Questionnaire (MPQ) and match as closely as you can with one of the profiles derived from many prior lost-person searches. Here is a list of the profiles available in one of the authors' published work (Koester: *Lost Person Behavior*[12]) and the corresponding smartphone app (also *Lost Person Behavior*):

Abduction
Aircraft
Angler
All-Terrain Vehicle (ATV)
Autistic
Car Camper
Caver
Child (Toddler) 1 to 3
Child (Preschool) 4 to 6
Child (School Age) 7 to 9
Child (Pre-Teenager) 10 to 12
Child (Adolescent/Youth) 13 to 15
Climber
Dementia
Despondent
Gatherer
Horseback Rider
Hunter
Mental Illness
Intellectual Disability
Mountain Biker
Other
Runner
Skier-Alpine
Skier-Nordic
Snowboarder
Snowmobiler
Snowshoer
Substance Intoxication
Urban Entrapment
Vehicle
Water-Related
Worker

If the subject was riding a mountain bike, or was autistic, was a child, or was hunting, you can select a corresponding profile and use the statistical data to help delineate the search area, segment it, and assign priorities to the segments based on this information. For example, if you are looking for a hunter in a temperate climate in the mountains, a quarter are found within 0.6 miles of the IPP, half are found within 1.3 miles of the IPP, 75% within 3 miles, and 95% within 10.7 miles. Seventy percent are lost, 22% are simply overdue, and illness and injury account for only 3% (2% medical, 1% trauma). Additional statistical models are based upon direction of travel (dispersion), elevation changes,

track offset (distance away from linear features, watersheds, mobility, find feature, and specific points). This allows you to focus your search efforts in appropriate segments.

Geographic Information System

You can use a GIS to determine the overall search area and assign POAs to planning regions or segments based on elevation, roads, and trails. Given known travel time formulas, your GIS can plot how far the subject may have traveled in different directions. Thus, you can estimate travel times from the IPP. In the early stages of a search, you may be able to search only a small area, as the subject could only have traveled a relatively short distance. Given the elapsed time since last seen, a GIS can easily plot on the map an estimate of travel times from the IPP. This will not be a perfect circle, as the subject could have traveled faster along roads and trails. If there is a network of roads and trails in the area, the GIS does a much better job of estimating travel times than a human.

POD (Probability of Detection) and Sweep Width

For this theoretical framework to help search managers in the real world, we need a reliable way to assess the POD for various search tactics. For searching at sea, where the environment is very uniform, tables are available. But for wilderness SAR, with widely varying environments and weather, POD values are just beginning to be known. The old traditional method—while debriefing the Field Team Leader (FTL), ask for an estimated POD—is likely very inaccurate. The most recent work in estimating wilderness search POD involves actually measuring something called *effective sweep width*, which is essential to determining POD.[5,9,20,21] Sweep width is a measure of the detectability of a particular search object for a particular searcher (sensor) in a particular environment. It can be considered a detection index. The detection index will vary, not only in different types of terrain (desert, forests, meadows, alpine tundra, brush), but along a search path, depending on how much brush there might be at a particular point. Nonetheless, determining an average effective sweep width for a searcher (eg, air-scenting dog: olfactory; human searchers: visual and auditory) in each environment (open forest, brush) gets us a much more reliable estimate for the actual POD than the "FTL's best guess" method. In a 2003 report to the Department of Homeland Security, search experts recommended research efforts to determine sweep width values for land search.[6]

Wilderness SAR team members sometimes practice and assess themselves by having someone leave clues in a practice area, then have a field team search the area to see how many of the clues they can find. Under controlled conditions, a similar exercise can allow researchers to determine *effective sweep width*, almost always shortened to *sweep width* in common speech.
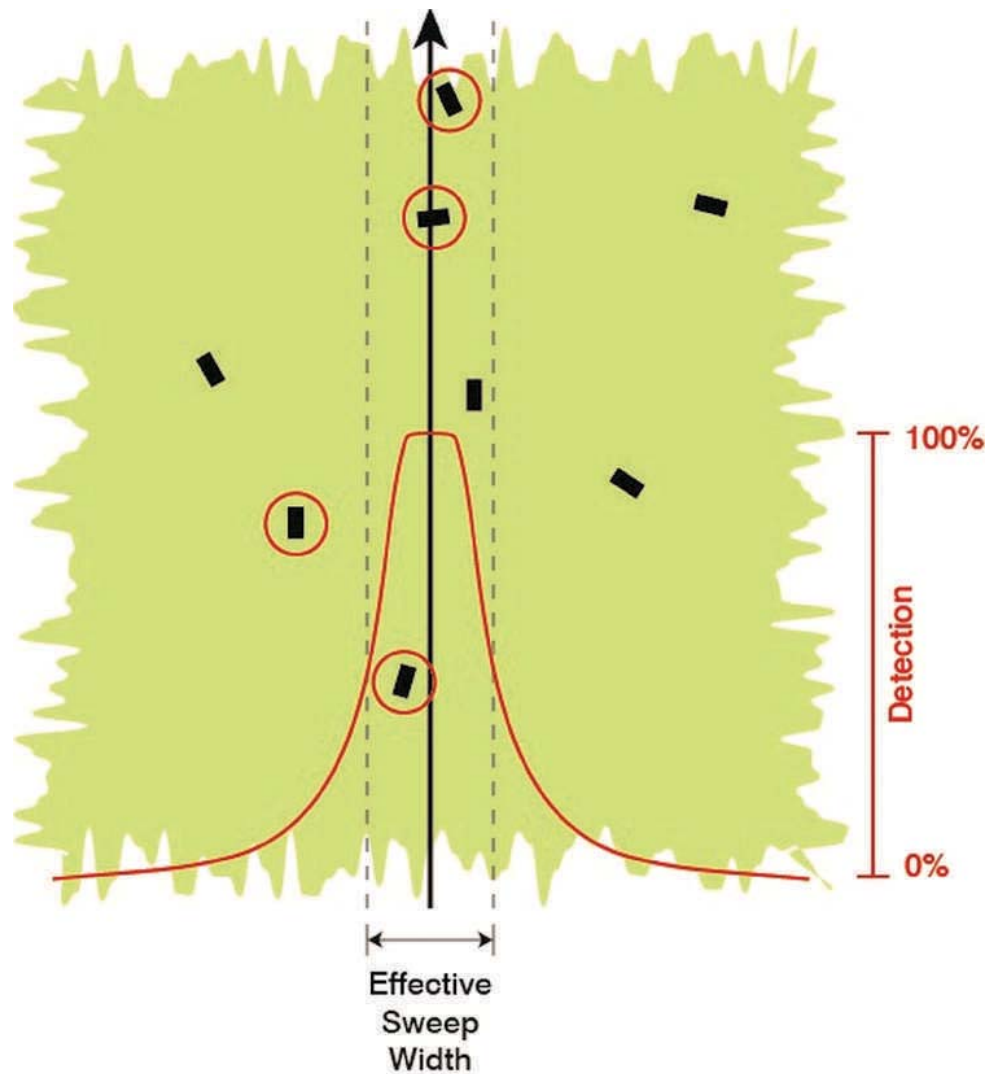
FIGURE 30.4. Effective Sweep Width, Top View. This represents a search resource—for example a searcher, or a field team of trained searchers—moving across a search area. The superimposed red curve represents the ability of the tactic to detect objects (responsive or unresponsive subjects, or clues); the shape of the curve likely varies quite a bit depending on the search tactic and the terrain and weather. The shape of the curve here is arbitrary. Detection is high directly in line with the team, but tails off on either side. The effective sweep width ("sweep width") is represented by the dashed lines. Illustration by Keith Conover, MD, FACEP. Used with permission.

"The effective sweep width may be thought of as the width of the swath where the number of objects inside the swath that are not detected equals the number of objects that are detected outside the swath."[9] This is illustrated in **Figures 30.4** and **30.5**. The advantages of sweep width over other models of search detector range are that it is more easily manipulated mathematically and can actually be determined by experiment. In fact, since the sweep width integrates the actual environment, it can *only* be determined by experiment at this time.

If you use a simulated body (a dressed human manikin) as the subject, the sweep width is for an unresponsive subject and requires visual search; if you use a live person who is coached to answer a searcher's calls, the sweep width is for a responsive

subject and uses an auditory search. If you use a standard "clue" such as a quart milk carton painted orange, then the resulting sweep width is for a clue of similar size and color.

Research efforts are now deriving actual sweep width numbers for human and canine searchers in different terrain and vegetation.[7,8] It is also possible now to use a much shorter field experiment taking just a few minutes to obtain an estimate for the sweep width value for the particular task area about to be searched.[8] This allows (somewhat) evidence-based estimations for the POD term of that central equation of ground search theory, POS = POA × POD.

If we know the area (segment) a team has covered without finding the subject, the effective sweep width of their search technique in the given terrain, and the effort of the team, we

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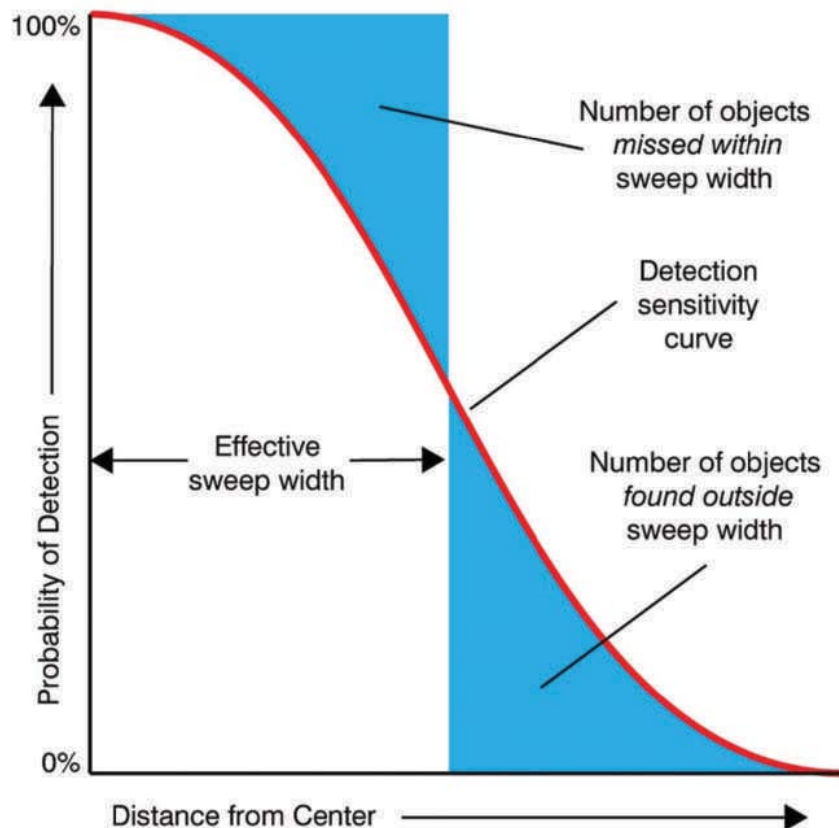
FIGURE 30.5. Effective Sweep Width, Mathematical View. If we know the segment searched, the tactic used, and the sweep width and spacing of the tactic, we can calculate the probability of detection (POD) for that segment. This can then be used to modify the probability that the subject is in the area (POA). Illustration by Keith Conover, MD, FACEP. Used with permission.

can calculate a revised POA for that segment: an opinion about how likely the subject is in the area, revised downward based on the efforts of the search team.

Shifting POA and Other Complications

Once a segment has been searched, it is less likely that the subject is in that segment, and your attention will usually turn to other segments. You can quantify this through the process of *shifting POA*: if you know the POD of a resource that has searched a segment, you can calculate how much less likely the subject is in that segment, deriving a new POA for that segment. Then, you (or more realistically, your computer) can calculate how much higher this makes the POA for all the other segments. This allows you to direct subsequent tasks to the highest-probability areas. It is also possible to calculate a *cumulative probability of detection (cumulative POD)* for an area that has been searched multiple times. However, "no mathematical method can be allowed to take the place of good judgment in the field. The mathematics in this Addendum provides valuable decision aids, but cannot make decisions; mathematics only processes the available data and may not

account for important, operationally significant realities. On the other hand, while pure intuition is easier to use, it is harder to justify later if success does not come early and if is not as reliable in the long term. Use the mathematics as a guide, but not as the complete answer."[3]

For example: segment 5 was searched by an air-scenting dog who alerted twice when near the border with segment 8, but then lost the scent. Was this the subject being scented, or perhaps a hiker or hunter passing through segment 8? It certainly increases the POA for segment 8, but by how much? And what if, at the same time—remember this is a dynamically changing situation—a field team in segment 4 found a fresh gum wrapper of the type the subject was known to be carrying?

This can get very complex, very quickly. However, the basic idea of the Mattson Consensus—that many heads are better than one[*]—has been around for a long time, and its truth well documented in the literature, as summarized in the popular book *The Wisdom of Crowds*.[22]

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[*]The earliest we could find this phrase in English was in an 1811 edition of *The Examiner*, but it probably predates this; the concept dates back at least as far as Aristotle.

It is hard for our minds to mathematically quantify how various clues affect the search strategy, or even to quantify the *uncertainty* of the effect it should have on search strategy. Indeed, in the Mattson or similar consensus methods, Mattsoners are asked to quantify their certainty/uncertainty about where the subject is for different search area segments; perhaps there is also a way to quantify Mattsoners' certainty or uncertainty about these estimates. This is a great opportunity for those involved in the mathematical and computer science field of fuzzy logic. And, since few, if any, search managers naturally think in terms of matrix algebra, this is also a challenge to software engineers to develop a matrix calculation system that employs fuzzy logic. It will also need an intuitive graphical user-interaction design that corresponds with human mental models, allowing accurate entry of incoming information and meaningful presentation of the results.

Limits to Search Theory

As with the physicist's recipe for fried chicken ("First, assume a spherical chicken. . ."), there are some issues in trying to apply search theory to actual searches. An underlying assumption of much search theory (developed for maritime search) is that the POA is a circular normal distribution (very much like the physicist's spherical chicken). This is a somewhat reasonable assumption for searching for a warship or a life raft from a patrol airplane if we ignore local areas of mist or fog or sun reflection, or observer fatigue. But both mathematically and in real life, wilderness lost-person search is much messier. Assumptions about probability distributions must be extensively modified for varying elevation, terrain, vegetation, impassible barriers, easy travel routes, and the like. This is why a combination of human input via a Mattson Consensus and several different statistical models provide the best input to the search planner.

For determining sweep width and POD, it is easier to find a subject who is screaming "Over *here*! I'm over *here*!" than to find a subject who is unconscious or dead. And searchers, at least well-trained ones, search for clues as well as subjects. So, the POS = POA × POD equation is complicated by the fact that different resources and tactics have different PODs for responsive and unresponsive subjects, and we do not really calculate POD or POA for clues. A recent report in the literature helps quantify the brief difference between visual and auditory searching.[23]

But these theoretical constructs, even if they cannot always be directly applied to search operations, especially for wilderness SAR, nonetheless inform our decisions about how and where to search, and are part of the training and mind-set of any effective search manager.

Going further into search theory can rapidly get both complicated and controversial and we will remand those interested to take a course such as *Managing the Lost Person Incident, Managing Land Search Operations, Managing the Inland Search Function,* *Managing Search Operations* or the joint U.S. Air Force—*U.S. Coast Guard Basic Inland SAR Course*[*] or *Inland SAR Planning Course.*[†]

SEARCH MANAGEMENT

The most basic SAR team capability is search. Even if someone comes out of the woods/desert/mountains/cave and says "my buddy fell and broke his leg!," finding the injured person can still be taxing. Often the person coming out with the message is too exhausted/dehydrated/cold/hot to serve as a guide to the injured person. And, even if physically able to serve as a guide, his or her memory and navigation skills may not be up to the task.

Initial Operations and Reflex Tasks

In emergency medicine, we sometimes follow an internal-medicine-ish model: gather data, formulate a diagnosis, then come up with a treatment plan. But sometimes, as with a Level I trauma patient, we follow a trauma-surgical model: do a standard trauma exam and start a standard resuscitation protocol all at the same time, to make sure important things get done quickly.

The type of search management we have discussed thus far—gathering data, doing a Mattson Consensus and the like—takes time, and is an internal medicine-type approach. But for the first hours of a lost-person search, a trauma-surgery approach is better: A standard part of modern search management is to get people out into the field as soon as possible. You do this by starting *reflex tasks*: Basically, as soon as you have enough information to send a team into the field, you do so.

In the future, we may want to dispatch a reflex task using an unmanned aerial vehicle (UAV, also known as a drone) to survey the area. UAV information may identify areas that are best for certain types of tasks. For large grassy areas or fields, a UAV's camera, combined with humans interpreting the still pictures or video, may provide a high POD much faster than a human or even canine field team can. Given how quickly a UAV can get to and search an area, it may have a far better PSR than a human field searcher.

For lost-person searches, SAR team members tend to arrive at Base not all at once but in dribs and drabs. As soon as enough people arrive at Base to create field teams, even before you have detailed information you get teams out to what seems like high-probability areas, almost always as hasty tasks. These field teams may not have a complete briefing, but they can get more information via cell phone or radio. You can re-task a team if you get new information and decide that somewhere else has a

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higher POA. But by that time, you usually have enough people to dispatch additional field teams to those areas.

This is one situation where remote support may help; when SAR team members first set up a base and plug in the laptops and printers, remote support personnel have already generated some reflex-task Task Assignment Forms (TAFs; more later on this) and maps that can be printed right away.

The initial information you gather, which you should record on a MPQ (more on this later), along with any other relevant data (such as location of the subject's car, or any reported sightings) helps you establish the two most important points in a search: the PLS and the LKP. They are often but not always the same. You will choose one of the two, likely based on the reliability of the reports, as the IPP. An ideal reflex task is to send a couple of clue-aware searchers, or better yet credentialed man-trackers, to cut for sign around the IPP.

Initial searching can be a *point search*, for example, checking the area around where the subject's car was found. Small teams of searchers are also usually sent out to search along trails and streams, as lots of lost people turn up along trails or streams. These are called *hasty search* tasks, as you are instructed to move quickly, at least more quickly than a line of searchers moving through the woods, trying more to locate a live subject than clues. If your field team is assigned a hasty search task, you will likely be sent out with instructions to search a linear feature, usually a trail or stream, and along with a Task Assignment Forms (TAF; more on that later), your FTL gets a map with the linear feature highlighted, attached to the TAF.* It is traditional, particularly in the eastern United States, but by no means universal, to letter Field Teams by the international-standard ICAO-ITU (International Civil Aviation-International Telecommunications Union) phonetic alphabet: Team Alfa, Team Bravo, Team Charlie… and to number tasks. Team Alfa will probably be assigned Task 1, but once they are done with that, they might be assigned over the radio to Task 8.

Dog teams are sometimes simply named after the name of the dog. Dog handlers strongly favor this as it makes their job easier: they do not have to remember a team name. Purists object on several points. First, this might end up causing confusion between two teams named Charlie or Romeo or Sierra, though the likelihood of a dog named Foxtrot or Hotel seems remote. A more salient point is that the ITU-ICAO phonetic alphabet is designed to be easy to hear and understand when those communicating are under stress, or communications are less than clear, and people only need to discern 26 separate words. That is not true of dog names: there are many, and some may be hard to understand or to spell, which can lead to confusion.

A common teaching and memory tool for the initial phases of a search is the Bike Wheel Model (see **Figure 30.6**; **Table 30.1**).

*No specialty is complete unless it is rife with three letter acronyms (TLAs).

In this analogy, the axle is the IPP. The hub is initial search area right around the IPP. The rim is the rings that describe the 50% and 95% probability areas. The spokes are linear features (roads, trails, powerlines, streams) leading from the hub out toward the rim: ideal linear hasty search tasks. Reflectors are areas of special interest: attractions such as mountain peaks, hazards such as places where it is hard to follow the trail, or simply places where lost people seem to end up.

Ramping Up to a Big Search

Whether in the city or in the wilds, finding lost people is usually considered a law enforcement function, so it is usually the local law enforcement agency—sheriff or police or park/forest rangers—who handle the initial call and perform the initial investigation; sometimes, they will perform some of the initial searching, too. But when an individual or a group is overdue after a trip into the wilds, and as time goes on and more and more and more people and organizations get involved in the search, finding them can get complicated, and more complicated, and more complicated, not in a linear but in an exponential fashion. Given the time pressure, organizing the searchers can be a nearly overwhelming challenge, which is one reason the Incident Command System (ICS) is essential for such large operations. ICS for WEMS and SAR operations is described in more detail in Chapter 3. In addition to the organizational challenges, the operation needs people expert at the specifics of search management to serve in Base, and people expert at search tactics to serve in the field. This is often met by local wilderness SAR teams, who supplement local law enforcement and generally work under their direction. Getting such professional volunteers involved early allows local law enforcement to keep a grip on the operation, especially as less-well-trained responders (fire, EMS, others) show up and need to be managed by trained search managers in Base and led by trained leaders in the field.

Unless you find the person right away with hasty search tasks, a lost-person search becomes a mystery, and to solve a mystery you must search for clues. While teams search for clues in the field, many clues are found *not* in the field. There is a saying in medicine that 80% of the diagnosis comes from the history, and only 20% from a physical exam and laboratory tests. The same thing applies to lost-person search: The best and most clues come from gathering a history. What's the lost person's name? Physical description? Fitness and medical conditions? Outdoor experience? Clothing and gear? What was he or she doing: Hiking? Climbing? Hunting? Fishing? Where was he or she going? When was he or she supposed to be back? Did he or she mention alternate routes? Was he or she despondent?

While a search in the United States almost always runs under the ICS—and wilderness SAR teams are expert at using the ICS and its forms—there are two additional forms that
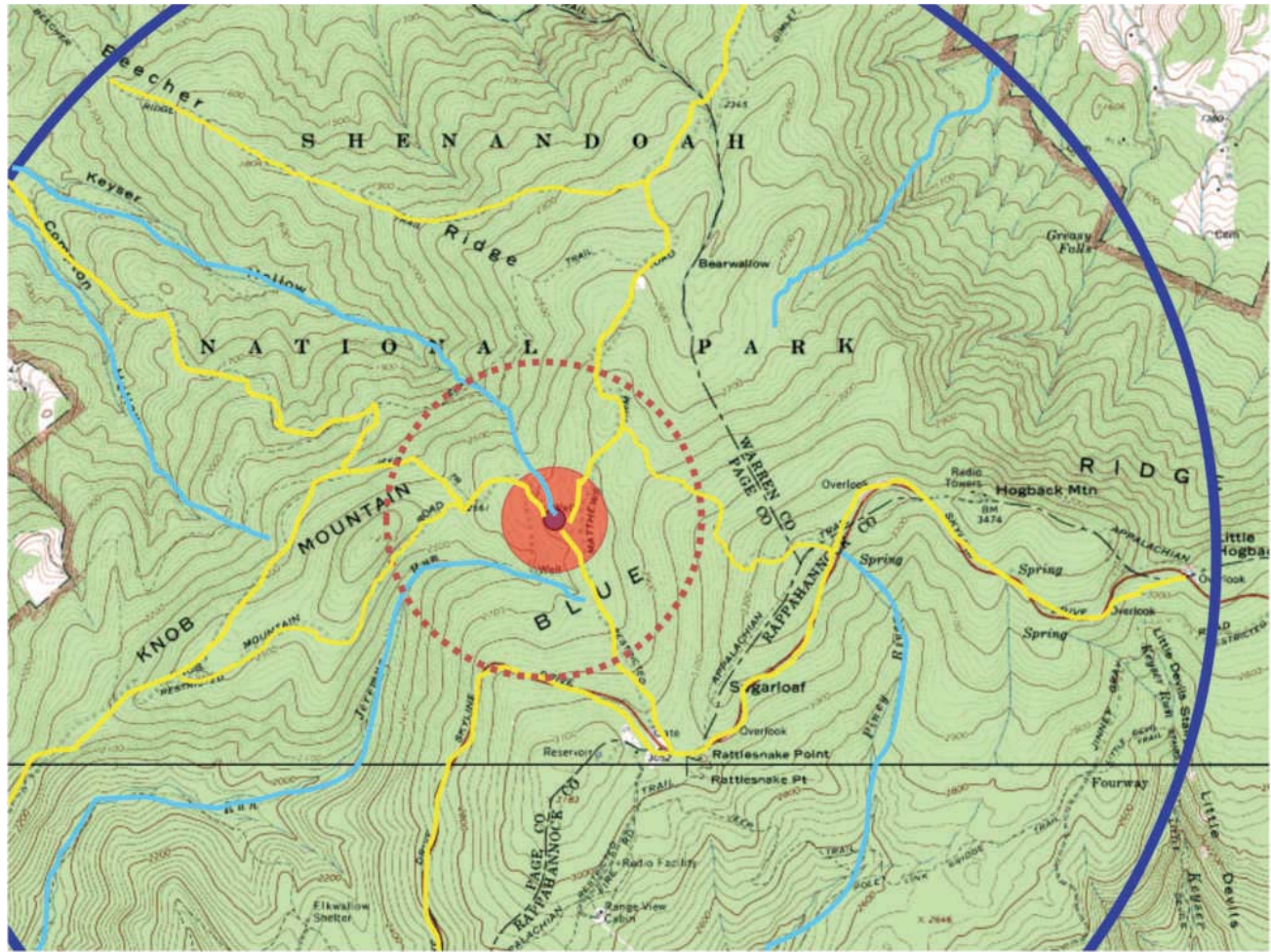
FIGURE 30.6. Map of bike wheel model.

wilderness SAR teams almost always use. One, the TAF, we will discuss later. The other, the MPQ, is used to help gather this information. You can find an evidence-based MPQ in an appendix to *Lost Person Behavior.*[12] Law enforcement officers are generally very good at investigating missing person situations, but when it comes to a person lost in the wilderness, sometimes SAR teams find additional information helpful, and the MPQ is very helpful in preventing you having to go back and say "there's one more question I need to ask…"

A large lost-person search operation will put hundreds of people in harm's way. It will juxtapose many different agencies and organizations, with different cultures, procedures, and goals. Just to keep the people and agencies working together without bloodshed is a test of any manager's capabilities. Getting all of them to cooperate in doing an effective job is an ever-bigger challenge. While similar in some ways to managing a large wildfire, lost-person search has its own peculiarities. And this usually happens at a place with little or nothing in the way of food, shelter, electricity or communications, which nonetheless becomes a place called Base. The ICS calls the place where the

Command Staff is the *Incident Command Post* (ICP), reserving the term *Base* for a logistical center that may be at a different location.[24] But for lost-person searches, Base and the ICP are usually co-located. And, since they first evolved in the 1940s or so (long before the ICS), wilderness SAR teams have used the term "Base" and this seems likely to persist. On the radio, it is easier to say "Base, this is Team Alfa" instead of "Incident Command Post, this is Team Alfa," which tends to reinforce this usage.

Search Management Processes and Technology

The ICS was developed to deal with wildland fires, and then mandated for intergovernmental incidents in which the U.S. Federal government is involved. Almost all non-Federal emergency service agencies in the United States have adopted the ICS, with variable degrees of penetration. While most EMS personnel have some familiarity with the ICS, it does not much affect their day-to-day operations. But SAR personnel eat, drink, and sleep thinking about the ICS, because they use it almost every time

Medical Interface with Technical Rescue Operations

Table 30.1 Reflex Tasking Using the Bike Wheel Model

Reflex Tasking	
Axle	
1. Plot the Initial Planning Point (IPP)	• Preserve • Immediate locale search • If a structure, search and re-search repeatedly • Signcutters/trackers • Tracking/trailing dogs
Rim	
2. Determine subject category. 3. Determine statistical ring. 4. Draw 50% and 95% rings. 5. Reduce search area using subjective and deductive reasoning. 6. Mark boundary on map.	• Establish containment. • Consider camp-ins, road/trail blocks, track traps, patrols, attraction, and string lines.
Hub	
7. Mark 25% ring if appropriate.	• Canvass campgrounds, if appropriate. • Thoroughly search from IPP to 25% when less than 0.2 miles/0.3 km.
Spokes	

8. Draw travel routes:
   a. Blue lines (water features, drainages)
   b. Dashed lines (trails)
   c. Black/red lines (roads, man-made features)
   d. Travel corridors (ridges, contours)
   e. Corridor tasks, if appropriate
	• Conduct hasty search of trails, roads, drainages, and other travel routes leading away from IPP.
	• **Emphasis at likely decision points.**

Reflector	
9. Mark high probability/hazard areas 10. Prioritize and deploy tasks using quick consensus method	• Send hasty teams to areas of high probability, high hazard, historic locations of finds.

© 2011 by dbS Productions. Adapted from *Lost Person Behavior* by Robert J Koester. Reproduced with permission.

they respond to an operation. The ICS itself is designed to be an all-risk[*] incident management system that can be applied to almost any incident, and in this it succeeds, with the degree of success dependent on the participants' knowledge of, and compliance with, the ICS. However, some search managers find the ICS forms unsuitable for large or even small lost-person searches. For example, the ICS Form 207 (table of organization) for decades betrayed its roots in wildland fire by having a box for "Air Tanker/Fixed Wing Coordinator." The ICS forms have evolved to be more general-purpose and generally better, but specialized forms for lost-person search, which predate the ICS, remain in use by many SAR teams, though they too have evolved over the decades.

In 1992, Conover (one of the authors) developed, as a draft for discussion within the Pennsylvania Search and Rescue Council, a set of ICS-type forms specific for running a lost-person search operation. These forms, including a non-ICS MPQ and non-ICS TAF, were immediately adopted without discussion and are still used today in Pennsylvania for lost-person searches, but may be freely used in other jurisdictions.[†]

A TAF, shown in **Figure 30.7**, is central to lost-person search management. Search managers have tried a variety of means for tracking individual field teams, including the T-cards[‡] used by the wildland fire service, and various computer-based systems. But since the TAF was developed by the ASRC in the mid-1970s,[§] it has been enduringly popular for managing the many teams and tasks required for a large lost-person search. Indeed, the *ICS Form 204*, which started as the *Division Assignment List*, has slowly evolved to look more like a TAF and is now called *Assignment List*.[25]

The ICS Plans Section (Plans) fills out the upper portions of the TAF's front page, indicating *what* they want done, and *how* they want it done. The Plans section then hands a pile of TAFs to the ICS Operations Section (Ops), which then matches the tasks with the searchers (*who*), both human and canine, and completes the middle sections as they dispatch teams into the field (*when*). When teams arrive back in Base, or complete a task and report in via radio or cell phone, the Ops Section works with the FTL to gather useful information from the team's task. Ops then

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[*]In simple terms, that means it works for a forest fire, a lost person search, or a visit by the Pope or the Queen of England.
[†]http://conovers.org/ftp/PSARC-Archive/PSARC Forms/sarfrm10.pdf

[‡]T-shaped cards that can be inserted in slots on a large rack for easy viewing and manipulation.
[§]http://archive.asrc.net/ASRC-Operations/ASRC-Operations-Manual/1976-09-00-ASRC-Operations-Manual-V.pdf.

Task Assignment Form (TAF)

by **Plans**/**Ops**   ≈ICS 204   once-per-task form

Describe Task

Incident Name	
Incident Number(s)	
Date	
Operational Period	
Task Number	
Priority	
Map(s)	
Created by	

Hasty (Type I: speed over thoroughness)
Sweep (Type II: mix of speed and thoroughness)
Line (Type III: thoroughness over speed)

Airscent Dog

Trailing Dog

Mantracking/signcutting

Check when briefed (enter details above)

- ☐ Expected duration
- ☐ Clues to seek
- ☐ Expected POD subj/clue
- ☐ Subject info
- ☐ Teams nearby
- ☐ Hazards/safety
- ☐ Terrain/weather
- ☐ Press/family plans
- ☐ Find/Rescue Plans
- ☐ Previous Efforts

Equipment Needed & Transport

Team Name	
Briefed by	
Date/time	
Briefed	in person @ Base ○ Radio/cellphone ○

List of additional personnel attached ☐

FTL	ATL	Medic	RS	RO	Name	Agency	FTL	ATL	Medic	RS	RO	Name	Agency
☐	☐	☐	☐	☐			☐	☐	☐	☐	☐		
☐	☐	☐	☐	☐			☐	☐	☐	☐	☐		
☐	☐	☐	☐	☐			☐	☐	☐	☐	☐		
☐	☐	☐	☐	☐			☐	☐	☐	☐	☐		
☐	☐	☐	☐	☐			☐	☐	☐	☐	☐		

Check in every ____ on the ☐ hour ☐ half-hour ☐ 15' past ☐ 15' 'til   Base phone ____

Team Callsign		Main freq.		Base phone 2	
Base Callsign		Secondary freq.		Team phone	
Other Callsign		Emergency freq.		Team phone 2	

Comms eqpt. issued/instructions ____

UTM/WGS84 ☐

Field Notes

Urgent followup ☐

Incomplete Task ☐

Completed Task ☐

Version 2.0 draft H 12/16   Created by Keith Conover of the Appalachian Search and Rescue Conference, with a lot of help from his friends. This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.   creative commons   Page 1 of 2

A

FIGURE 30.7. A, Generic task assignment form (TAF), first page. Upper portion completed by Plans Section, middle sections completed by Operations Section. This TAF is specifically designed to be used either as a printed form filled out with pen or pencil, or as a fillable PDF typed into on a computer. A PDF version of this form is available at http://www.conovers.org/ftp/ics-TAF-2.0h.pdf; updated versions will also be posted at http://www.conovers.org/ftp/. Illustration by Keith Conover, MD, FACEP. Used with permission. B, Back of generic TAF: debriefing. Completed when team returns to Base or reports completion of task over radio or cell phone. Illustration by Keith Conover, MD, FACEP. Used with permission.

Medical Interface with Technical Rescue Operations

TAF Back: Debriefing

Date/Time Prepared		Wind		Cloud Cover	
Task Length		Temp.		Other	
Search Technique		Precip.		Debriefer	

Check if discussed, explain below as needed

Adequate Equipment? Y◯ N◯   Map used? Y◯ N◯   [_____] Y◯ N◯
Adequate Personnel? Y◯ N◯   Map attached? Y◯ N◯   Areas not searched? Y◯ N◯
Problem-Free Task? Y◯ N◯   Map feature updates? Y◯ N◯   Weather/Terrain issues? Y◯ N◯
Able to Search Again? Y◯ N◯   Hazards? Y◯ N◯   Others in search area? Y◯ N◯

Describe areas searched and areas *not* searched

How searched?

Describe clues, tracks, alerts, hazards (also record on map)

FTL/ Debriefer Follow-Up Recommen-dations

FTL Sign [_____]

POD
Unresponsive/ Clues   FTL [___] %   Debriefer [___] %
Responsive   FTL [___] %   Debriefer [___] %

Task completed ◯
Task partly complete ◯
Urgent follow-up: fill in tabs on front ☐

Check to route, initial when reviewed

☐ Operations [_____]   ☐ IC [_____]
☐ Plans [_____]   ☐ Documentation [_____]
☐ Investigations   ☐ [_____]

B

FIGURE 30.7. (*continued*)

files the completed TAFs where Plans can use the information from them to plan the strategy and create the tasks (the top of the TAF) for the next operational period.

On small searches (which sometimes go on to become large searches), there may just be two people at Base, one who is mostly on the radio and another who does most of the paperwork; in this common scenario, there is not much differentiation into four standard ICS Sections. The person who is doing most of the paperwork and dispatching the teams, as opposed to issuing handheld radios and setting up and communicating using the Base radio, is mostly doing Plans and Ops, and this position has gotten to be called Plops. Really. And Plops' main job is to get the TAFs done and to get teams into the field ASAP. There is always tension between field personnel wanting to get into the field and Base personnel wanting to keep the paperwork straight. Experienced field personnel, especially those who have spent some time in Base before, recognize the critical importance of this paperwork, and will often help out for a bit until they go into the field.

ICS in the WEMS and SAR environment is discussed in more detail in Chapter 3.

SAR Technology

Technology affects all our lives at an increasing pace, and lost-person search is no exception. Pencil, paper, carbon paper, and the printing press sufficed to allow generations of search managers to develop sophisticated operational doctrines and procedures that saved the lives of innumerable people lost or injured in the backcountry, as evidenced by search management courses, and tools such as the PSARC forms packet and the TAF. "NCR sets," two- or three-part pressure-sensitive forms, are in common use particularly for TAFs, but represent just a minor improvement over carbon paper. Water-resistant two-part form paper for laser printing is now available, another incremental advance.[*]

Photocopiers came into wide use in the 1970s. Combined with clear acetate grid overlays, this allowed search managers to create gridded grayscale letter-size photocopies of USGS topographic maps. Having the same gridded map for the field team and the search base allowed much better communication of team and subject locations. For many years, a feature of searches was digging through a large supply of USGS topographic quadrangle maps to find the right one, then sending someone from Base, with an original USGS map and an acetate grid overlay, to a distant location where there was a photocopier, to prepare more maps.[†] While this type of grid system has mostly gone by the wayside, the acetate grid overlays are still sometimes pulled out to photocopy a park or forest map with much more trail detail than available from the USGS maps. Another use of this type of grid overlay is in cave search; given caves are three-dimensional, cave maps often include not only a bird's-eye (bat's-eye?) top view, but also side views of some cave passages, and even sketches showing how to find the entrance in a cliff. For example, Allegheny Mountain Rescue Group, which is also a cave SAR team, has PDF and printed cave maps with an extended ASRC grid added to the map, so you can use the grid coordinates to refer to a specific point on the side view or entrance-cliff sketch on the map.

Technology continues to change. Now we have GPS units, smartphone GPS/map apps, Universal Transverse Mercator (UTM) grids printed on USGS maps, and digital raster graphics (DRG) versions of USGS maps that can be printed, sometimes even in color on water-resistant or waterproof paper. The advent of laptop computers and portable printers has eliminated the need for a large cache of printed maps, and the routine use of acetate grid overlays for photocopying maps for field teams. (It does, however, makes having AC power or a generator at Base more important than it used to be.) It has also, to a degree, eliminated the need for a large USGS master map of the search, with clear acetate overlays with colored markings for each day's search efforts. Even the maps printed at Base are being threatened by maps that can be sent to a GPS unit or a smartphone GPS app, but given the vicissitudes of electronic equipment, battery life, and the small screens of GPS devices and smartphones, printed maps are still in demand.

Another significant advance was simply to have PDF versions of ICS and other forms that could be filled out on a laptop, and saved as well as printed. Laptops and printers are also threatening to replace much of the other paperwork of a large search operation.

Some of the earliest computer programs for SAR were to simplify the Mattson Consensus and other computationally intensive jobs such as dealing with shifting POA. One of the earliest such programs, in the 1970s, was CASIE[‡] (Computer-Aided Search Exchange), a DOS program which is now available in an updated Windows version.[§]

Another program that automates search planning and operations is *Incident Commander Pro*,[¶] which now integrates some GIS features. This software is known for its facility in dealing with trail-based POA calculations.

SARtopo[**] is a free, online shared workspace with USGS topographic maps. Multiple people can be looking at the same segmented map at the same time, and can associate data (usually

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*http://www.riteintherain.com, 2-part Carbonless Copier Paper
†A system for doing this is described in http://archive.asrc.net/ASRC-Operations/1982-12-02-ASRC-Grid.pdf. A set of graphic formats of the grid overlay may be found in http://archive.asrc.net/ASRC-Operations/2015-11-06-ASRC-Grid.zip.

‡http://math.arizona.edu/~dsl/casie/whatis.htm.
§http://www.wcasie.com/.
¶http://sartechnology.ca/sartechnology/ST_ProgramOverview.htm.
**http://sarsoft.org/, https://sartopo.com/.

called metadata) with a line or polygonal area on the map that represents a task. From the metadata for a hasty-search line or area segment on the map, SARtopo can generate a TAF-like printout. It is relatively simple to use.

An aggressive map-based approach has been spearheaded by Dr. Donald Ferguson of West Virginia University and the ASRC's Mountaineer Area Rescue Group. It uses the GIS *ArcGIS*, with specialized overlays, to prepare TAFs and maps. Called *Integrated Geospatial Tools for Search and Rescue (IGT4SAR),*[*] it is a free template. It is one of the best-known GIS-based SAR tools, so it is worth looking further at its capabilities.

ArcGIS is the best-known and most widely used GIS. It is a commercial product with a paid subscription; discounts are available to nonprofits such as SAR teams. Given that governments and agencies worldwide use it, *ArcGIS* is a mature product with more capabilities than SARtopo, though it is complex and harder to learn than SARtopo.[†] When using *IGT4SAR*, you deal with *IGT4SAR* more than the underlying *ArcGIS*, which makes the learning curve much easier. *IGT4SAR* can combine statistical data, such as that provided in *Lost Person Behavior*, with terrain and trail information to provide locale-specific probabilities, so you can assign POA to segments with some assurance of using the best information available.

Since the *IGT4SAR* maps are based on a GIS, they can have more detail than USGS topographic maps, such as updated trails; it is also possible to *georeference* (resize and align to fit the underlying map), for example, an overlay of a Park map that has lots of detail about trails and other features. The assigned task can be highlighted on the map electronically without the old standby of a highlighter on photocopied maps.

IGT4SAR can also generate TAFs for teams with attached maps, and keep a file of them for quick reference as needed. This replaces the standard *Tasks Planned*, *Tasks in Field*, and *Tasks Completed* folders that have been a feature of large searches for decades.

IGT4SAR also can provide printed maps with more information than standard USGS topographic maps, including updated trail information and communications coverage. Park and forest maps, with details of trails and facilities not available on USGS maps, are increasingly available in PDF or graphic formats. You can import one into IGT4SAR, georeference it, and overlay it to correspond precisely with the underlying topographic map. You can then print it out for field teams with standard map grids, serving as a supplement to a standard topographic map, or as a semitransparent overlay on a topographic map.

Dedicated GPS units with Automated Position Reporting Systems are sometimes issued to teams, which allows real-time tracking of teams in the field using *IGT4SAR*. Other teams have used satellite tracking devices to track teams when an Internet connection is available.

Team members with a GPS or with smartphones and a GPS app such as *BackCountry Navigator* for Android, or *Gaia* for the iPhone, can also record a track and add waypoints for clues or other important points. When they return to Base, they can use the smartphone's Bluetooth (or another method for dedicated GPS units) to download their GPS tracks and waypoints to a laptop computer where this gets associated with the record for that task in *IGT4SAR*.

Having all this information in *IGT4SAR* means that search managers may easily access the relevant data for a focused area. In the past, this meant dealing with many separate printed maps and TAFs, and multiple operational periods' individual clear acetate map overlays with segments, coverage and other information scribbled on them in different colors of grease pencil or marker.

A thesis providing an overview of the many uses of computer-based mapping for wilderness SAR is available online.[26] See also **Figures 30.8** and **30.9**.

The Department of Homeland Security Science & Technology Directorate First Responder Group is working with one of the authors (Koester) to develop software named *FIND*.[‡] FIND integrates GIS-type mapping (with a new custom topographic map), search theory, and search management. It is a turn-key solution and does not require any GIS-specific knowledge. FIND integrates all lost-person behavior spatial models to display a combined *heat map*, a graphic representation of the POA, where denser color or three-dimensional elevation corresponds to the POA. This allows search managers to assign POA to segments using what all the scientific, evidence-based models say about where the subject might be. It takes this one step further and determines a PSR,[§] perhaps the best measure of search effort, automatically.

If you do a Mattson Consensus, FIND will integrate it with the probabilities provided by the other models. It will then suggest initial search tasks for first responders, and use search theory to prioritize those tasks. As the search progresses, it will calculate PODs, shift the POA, and then update the probability of success values; thus, you can allocate your resources optimally. From an operations standpoint, it also tracks teams and tasks, using forms like the TAF. There are several dashboards that provide quick views of essential information showing how the search is progressing (**Figure 30.10** to **30.14**).

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*https://github.com/dferguso/MapSAR_Ex which also has a PDF available that explains the capabilities of IGT4SAR in much more detail than presented here; several video tutorials are posted on YouTube as well.

†Alternatives to ArcGIS, including free and open-source options, are available, but none that we know of provide powerful tools designed for lost-person search.

‡https://www.dhs.gov/science-and-technology/news/2016/09/01/snapshot-find-offers-simple-guidance-lost-person-searches.

§PSR is officially defined as *the instantaneous rate of change in POS for adding one more increment of effort (one more searcher) to a search segment.* Another way to understand this is *the probability of locating the subject per unit time.* The equation is $PSR = W \times V \times Pden$. It factors in the detectability of the subject W (sweep width), the velocity of the searcher V, and the missing subject's probability of area density for the search area of interest $Pden$.

Map Name: FF01

Planning #: P1115-007
Task #: T02-07

Incident Name: SkyMeadows-Doe
Incident Number: VA-000-15

Date: 11/17/2015
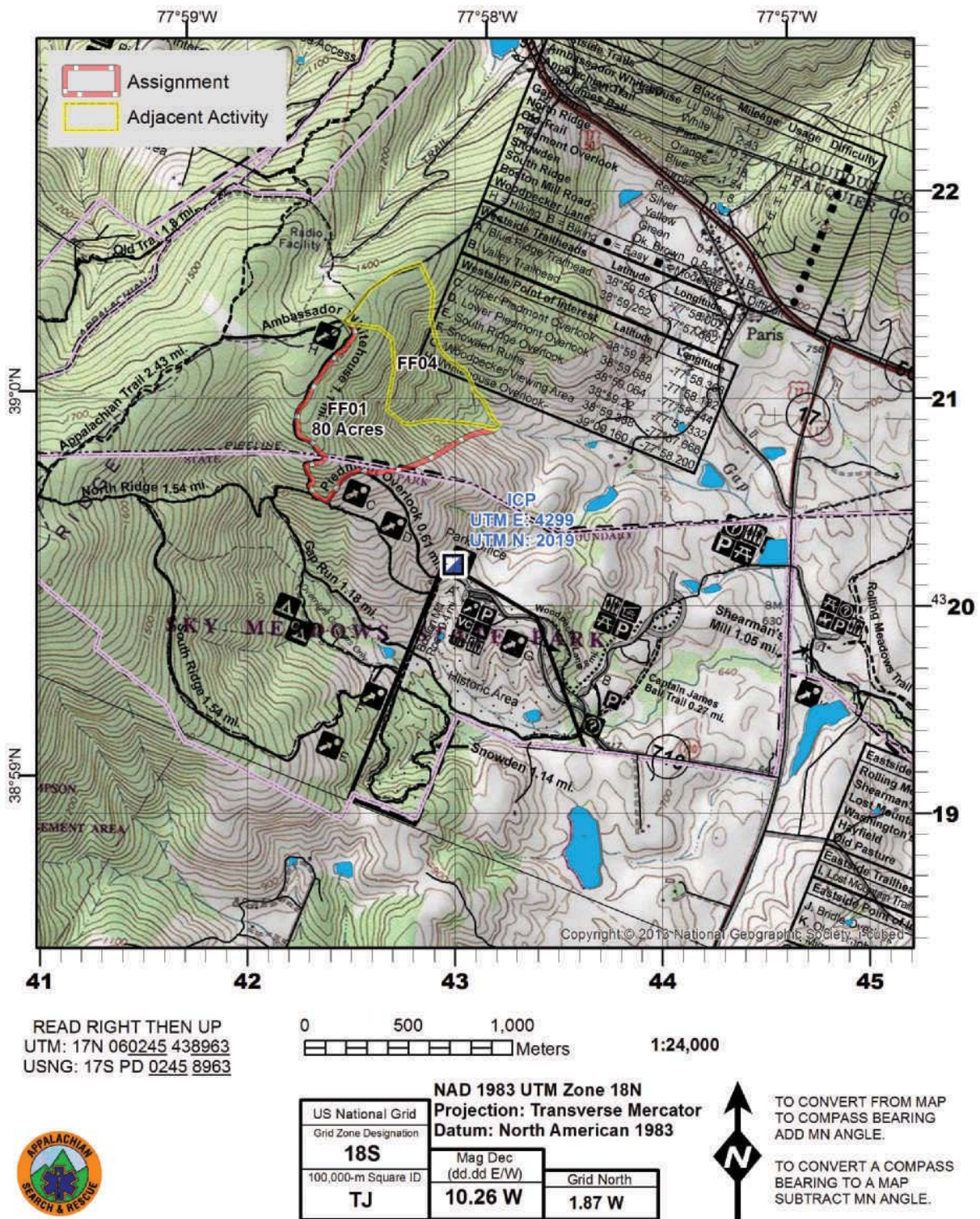
FIGURE 30.8. IGT4SAR Tactical Field Assignment Map. Produced by Integrated Geospatial Tools for Search and Rescue (IGT4SAR), this map provides Field Teams information regarding the location and surroundings for assigned task. Combined with a completed Task Assignment Form or ICS 204 form, this map should provide adequate information for the Field Team to conduct its assigned task effectively and safely. Illustration by Don Ferguson, PhD of West Virginia University and the Appalachian Search and Rescue Conference's Mountaineer Area Rescue Group. Used with permission.
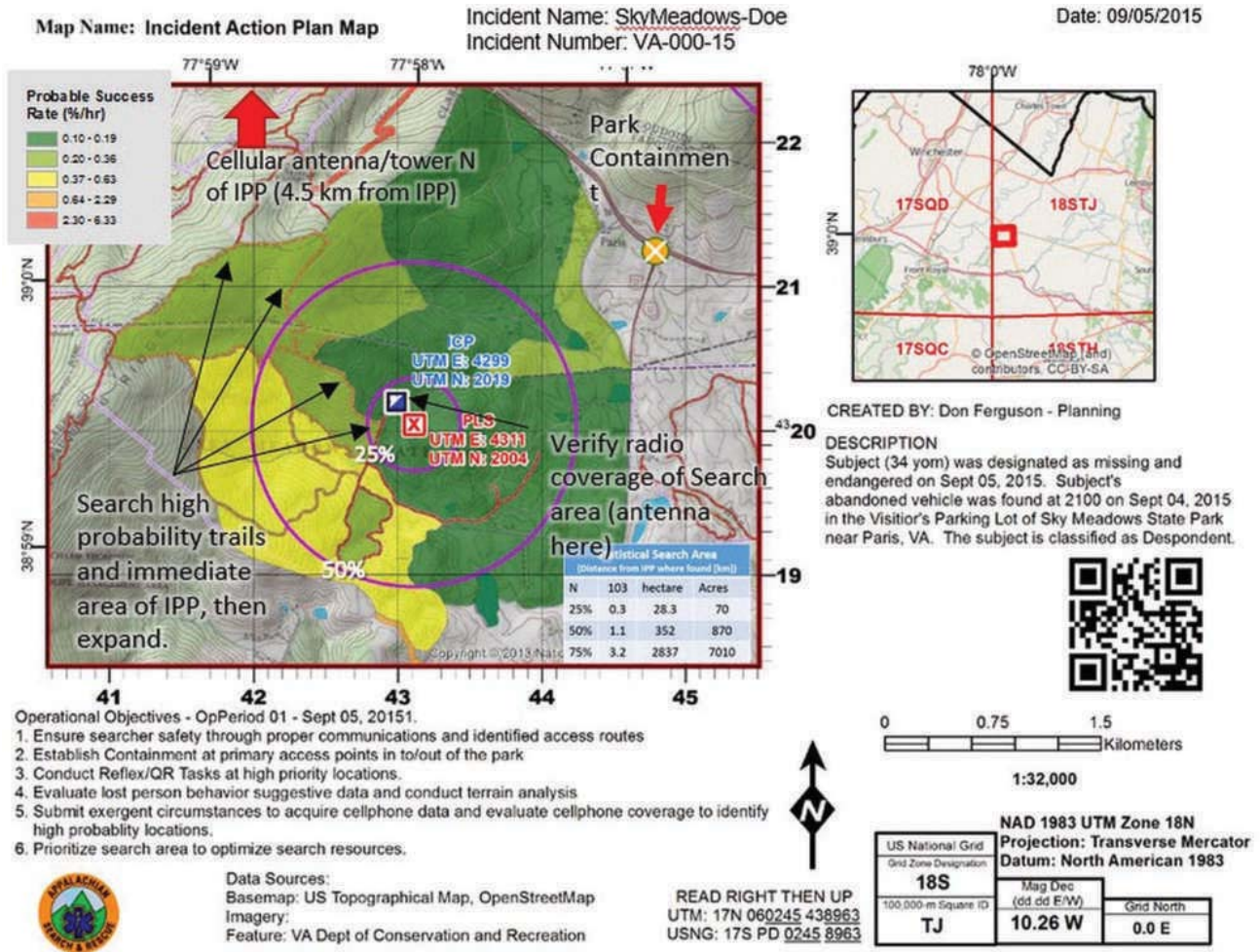
FIGURE 30.9. IGT4SAR Incident Action Plan Map. Produced by Integrated Geospatial Tools for Search and Rescue (IGT4SAR), this map and text effectively communicate geographic feature relationships and incident management objectives on an incident. This map is included in the ICS Incident Action Plan (IAP). Illustration by Don Ferguson, PhD of West Virginia University and the Appalachian Search and Rescue Conference's Mountaineer Area Rescue Group. Used with permission.

Remote Support

In the first two decades of the 21st century, we have developed technologies to allow people to collaborate remotely. And in the past few years, these technologies have become widespread and easier to use. Skype, Google Docs, Dropbox, and broadband on cell phones are well-known examples. This infrastructure now allows people who are far apart (perhaps even on a different continent) to work together for search management.

A truism for almost all lost-person searches is there are never enough trained-person-hours available in Base. Most search managers are also field-capable, and there is pressure to send just one more team out. And as a search ramps up in size, the number of Base personnel never seems to ramp quite enough to meet the need. Planning tasks and generating the TAFs and maps for the next operational period is one of the great time-sinks in Base, and doing it well takes even more time.

One way to meet this need for trained-person-hours in base is *remote support*. At its root, this just means getting someone who is not at Base to help. Here is a simple example. You know a retired park ranger who moved away from the area. But she has run multiple searches in this same area and knows where people tend to be lost. You look in your cell phone, find her new phone number, and give her a call for advice about which segments to search first. She answers, and you put your cell phone in speaker mode so the rest of your incident staff can hear the conversation. In a matter of minutes, her advice persuades your entire management team to reorder your segment priorities.

There are two problems with using remote planning, even in this simplest form. First, *realizing* that remote planning should be part of your procedures, and second, having a system for identifying and contacting such knowledgeable individuals. But remote planning can go far beyond this.
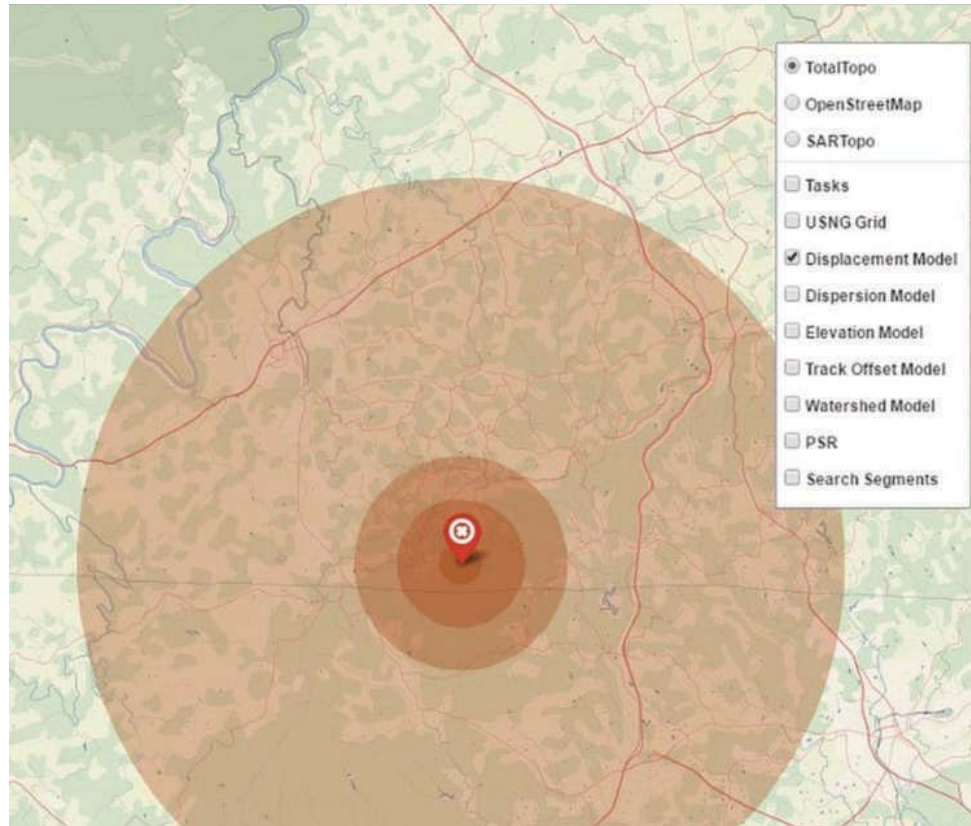
FIGURE 30.10. FIND Displacement Model Map. This and the following model maps show the model's prediction for where the subject is as a brown tint. The degree of tint corresponds with the probability density. The higher the probability, the darker the tint. Based on statistics specific to the subject's profile, such as in Lost Person Behavior, this map displays the probability density, for horizontal distance traveled from the IPP, as the crow flies. The outer ring boundary encloses the area with a 95% Probability of Area (POA). Each model is specific for subject category (eg, ecoregion domain, topology, and population density. Illustration by Robert Koester. Used with permission.

For a more technological example, you could be sitting at home in front of your computer in your bathrobe. With *IGT4SAR* you can produce TAFs and maps, or with *SARtopo* you can produce maps and TAF-like documents. You can then send them electronically, even with a low-bandwidth Internet connection, and those at Base can print them.

We should make a careful distinction between remote planning and remote *support*. Planning is likely the first technology-enabled remote support process for most SAR teams. But remote support can be more than just planning tasks for the next operational shift, that is, more than creating maps and TAFs. For example, remote support can also include analyzing UAV (drone) data, either stills or video, to identify potential suspicious areas which field teams should check.

One of the challenges of remote support is to develop such resources; SAR team members who have moved away are an obvious choice, but there may be other ways to develop such trained people. Another challenge is to develop a system to activate remote resources when they are needed.

DOWNED AIRCRAFT SEARCH

Wilderness SAR teams sometimes work with other organizations, such as the Civil Air Patrol, to find downed aircraft. Downed aircraft search is very different than lost-person search: containment's impossible, and the search area is vast. Satellites and aircraft may detect a radio signal from an Electronic Locator Transmitter (ELT), which has gone off when the airplane crash-landed or when those aboard the aircraft triggered it. (Many such alerts turn out to be from an aircraft in a hangar, when the ELT was accidentally triggered, but these are usually quickly dealt with.) Clues such as radar, flight-plan information, or cellular forensics (cell phone tower information) may also narrow down the search area.[27]

In such cases, vehicle-based teams may drive around the area, interviewing local people. They ask about low-flying planes, or planes that sounded like they were having engine trouble, or perhaps the smell of fuel, at about the time the plane was

Medical Interface with Technical Rescue Operations
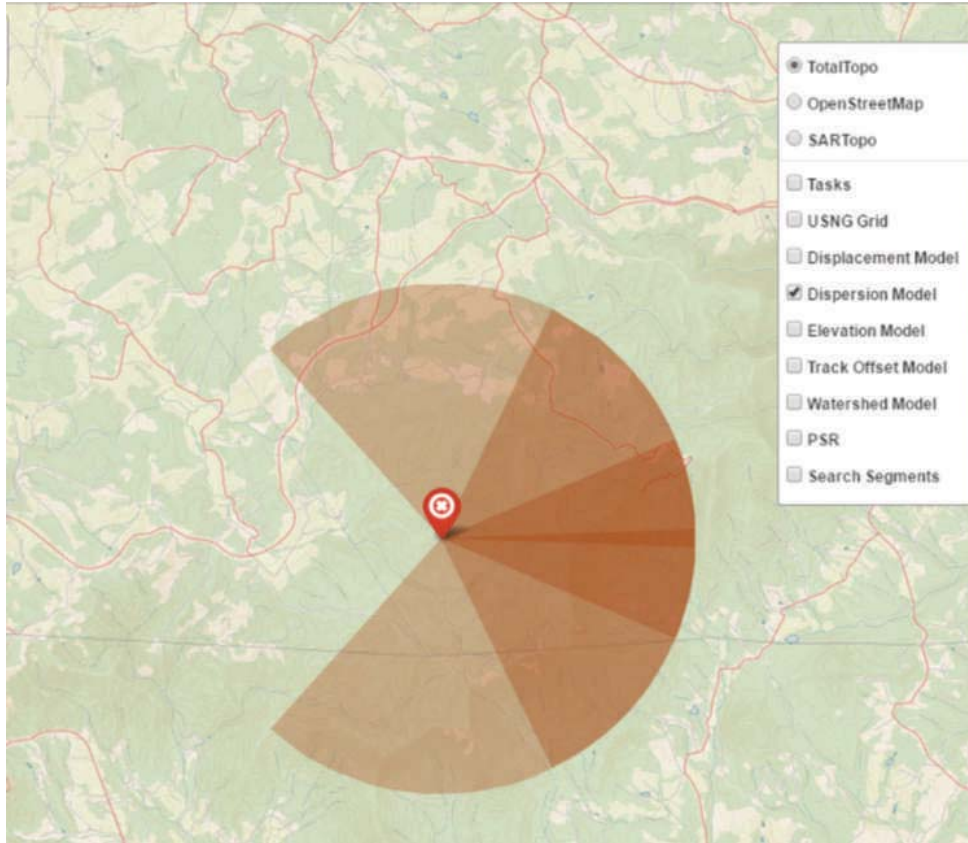
FIGURE 30.11. **FIND Dispersion Model Map.** Based on statistics specific to the subject's profile, such as in Lost Person Behavior, this map displays the probability density based on the angle between direction of travel and find location. Illustration by Robert Koester. Used with permission.

lost. They also sometimes take handheld ELT locators, special directional radio receivers that may pick up a signal. If they pick up a signal and are able to establish the direction, sometimes they can coordinate with other teams to triangulate on an ELT signal to get a more precise location.

Wilderness SAR teams are sometimes vectored in to a crash site by a low-flying aircraft or helicopter that has seen a possible crash site from the air. But if the forest canopy is thick, or it is not flying weather, field teams may need to search the area in a manner not much different than that for a lost-person search. ELT locators are small enough to be carried and are sometimes issued to field teams to use to close in on the crash site.

SEARCH AND RESCUE POLITICS AND REGIONAL VARIATIONS

As is famously true of volunteer fire departments and EMS services, SAR *turf* is a big deal.* We know that emergency ser-

*As far as we can tell from online searching, this term and the term *turf war* developed in the 1970s to describe the wars between urban youth gangs over which blocks they controlled. But it seems to us this term was in current use by volunteer fire departments even back then, so perhaps street gangs stole the term from the fire service.

vices workers, paid or volunteer, *need to be needed* and *need to be in control* and are *action-oriented.* These are important survival characteristics for emergency services workers, but predictably they lead to interpersonal and interorganizational conflict in emergency services organizations, particularly volunteer ones. If you search the Web, you can find videos of EMS agencies fighting over patients. If you are getting involved in WEMS, you are also getting involved in wilderness SAR, and being aware of such issues is critical to your success. As former Speaker of the U.S. House of Representatives Tip O'Neill[†] famously observed, "all politics is local," and the same might be said of wilderness SAR. And so a careful survey of the local SAR and EMS political landscape is important for anyone getting involved in WEMS.

An understanding of the personalities and organizations and their conflicts and alliances is critical, but it is also important to understand the official lines of authority and responsibility in the area. The sociopolitical organization of wilderness SAR teams in the United States is heterogeneous, not only due to local variation, but also in that it is very different in the East and

[†]December 9, 1912 to January 5, 1994; Speaker 1977-1987.
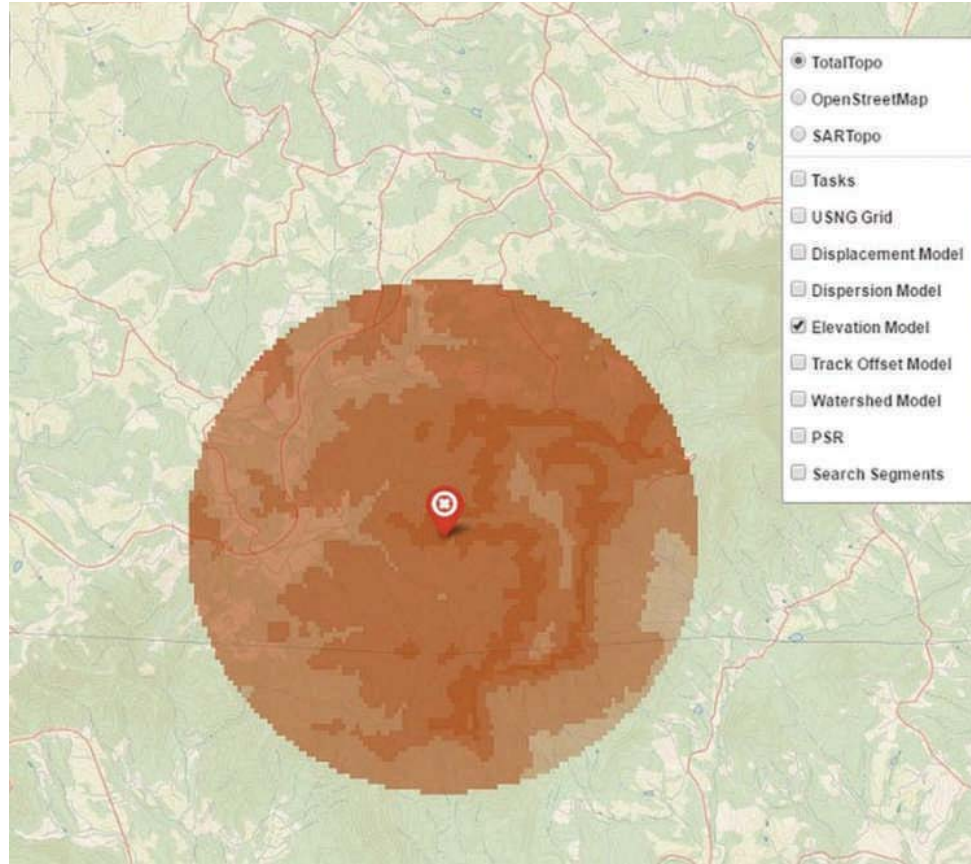
FIGURE 30.12. FIND Elevation Model Map. Based on statistics specific to the subject's profile, such as in Lost Person Behavior, this map displays the probability density based on the probability of the subject going uphill, downhill, or staying at the same elevation. Illustration by Robert Koester. Used with permission.

the West. The flatter central part of the continent has much less in the way of wilderness and thus fewer wilderness SAR teams.

In the western parts of the United States, each mountainous county tends to have a single SAR team, usually volunteer, but under the direct control of the sheriff's office. A deputy sheriff is usually appointed to be in charge of the team. Some of the larger western teams also have deputies who respond to SAR incidents on a regular basis, although in some of the larger counties (for instance, Los Angeles) sheriff's deputies are charged with SAR and provide the primary response. Counties with large urban areas tend to have several wilderness SAR teams, each with their own specialties, such as search dogs, high-mountain/alpine rescue, or four-wheel-drive vehicles. These teams may also be under the direct control of the sheriff's office as well.

In the eastern parts of the United States, counties are smaller, the mountains and wild areas are also smaller, and even rural areas are much more highly populated than in the west. In the East, given the higher rural population, the functions of eastern SAR teams are often carried out by the many local fire departments and EMS agencies. But there are also SAR teams that specialize in lost-person search management and wilderness rescue, usually covering a multi-county region, and which provide a backup or sometimes primary response to wilderness SAR situations.

FORCE PROTECTION

From a WEMS perspective, you should think about having 400 people out in the wilderness (or at least a relatively wild area) searching: the opportunities for illness and injury are impressive. Even for a small search or rescue, teams are sometimes in the field for a protracted time.[*]

The term *force protection* might suggest armed guards protecting against terrorist or criminal attacks. A more WEMS-oriented view considers it to include protection against illness and injury, and treatment of minor illnesses and injuries. The goal is to keep team members operational by providing simple medical interventions, often oral medications, that are generally outside the standard scope of practice of a street EMT or paramedic. The

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[*]https://www.fs.fed.us/fire/safety/wct/pdf03512805dpi300.pdf and http://www.conovers.org/ftp/SAR-Evacs.pdf

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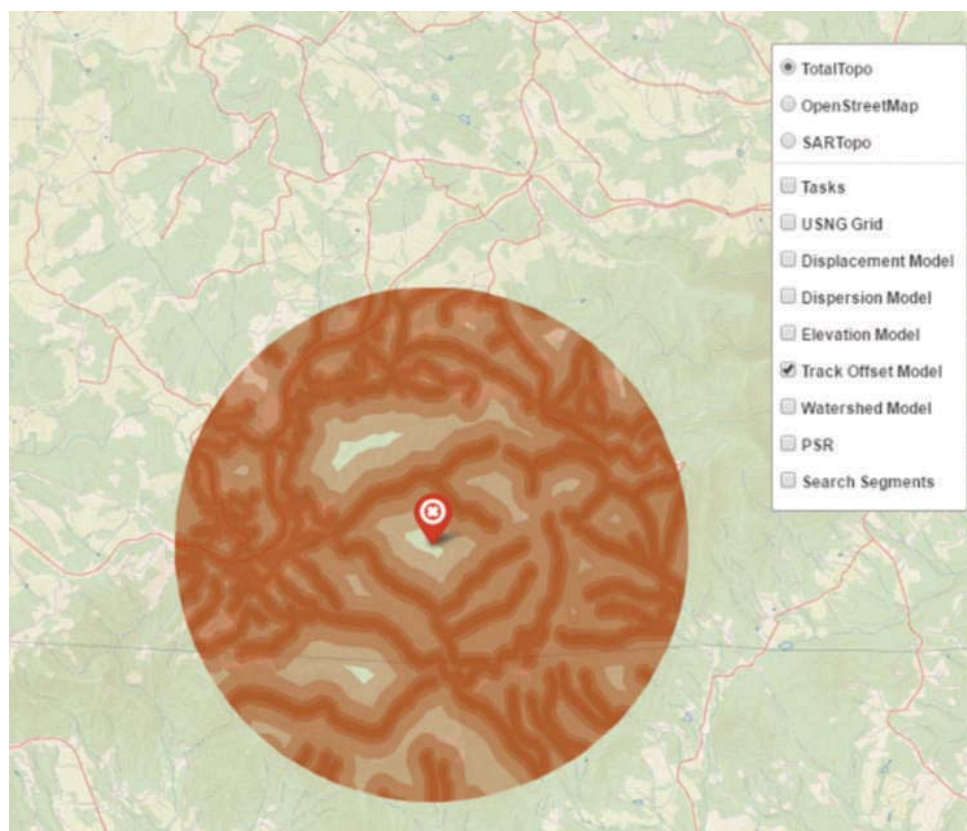
FIGURE 30.13. FIND Track Offset Model Map. Based on statistics specific to the subject's profile, such as in Lost Person Behavior, this map displays the probability density based on the probability of the subject's likely distance from a linear feature (road, trail, stream, or infrastructure). Illustration by Robert Koester. Used with permission.

target of this type of force protection is not the search subject or rescue victim, but the team members themselves.

Back in the day, the standard of care was to dispatch an unused funeral hearse to bring the patient to a hospital emergency room, literally a single large room with many cots in it. With the rise of EMTs and paramedics and well-equipped ambulances, it was said that the goal of EMS is to **bring the hospital to the patient**, but this stopped at the roadhead. Indeed, for many decades, Pennsylvania's EMS law extended *only* to care in or near an ambulance. We now might say, consistent with this tradition, that the goal of WEMS is to **bring the hospital (or many of its resources) all the way to the patient**, even if far from the road. If we continue in this vein, then you can think of force protection, not only as bringing part of the hospital's ED along with the team, but also as **bringing the urgent care center along with the team**.

We know from many studies that ankle injuries are very common in the backcountry, and there is no reason that SAR team members will be spared from this. If the EMS personnel on field teams are trained to apply the Ottawa Ankle Criteria, then they can determine in the field whether a team member needs X-rays or not. And if the team member does not need X-rays, then an urgent evacuation is not needed, and the ankle

can be taped and the member can either continue with the task or walk out if necessary. If necessary, another team could bring an air stirrup type ankle brace to aid in self evacuation, though this requires the preplanning to keep such braces at Base. Another example would be for teams to carry agents to control minor medical conditions such as diarrhea that could impair a member's ability to carry out SAR tasks (imagine if it is a cave rescue). Some of this material has crept into WEMT and Tactical Paramedic training: dealing with sprained ankles, blisters, and minor lacerations.

If it is a nice late spring or early fall day, environmental concerns for your searchers may be minimal. But during high summer or deep winter, force protection may also mean monitoring heat, humidity, cold, and weather and their effects on field teams. Arranging and staffing rest/rehab areas, with appropriate rehab for searchers, is another force-protection consideration. Force protection could include screening searchers heading to the rehab area for medical needs, and even more importantly screening searchers coming **out** of the rehab area for return to duty. These tasks sometime involve complex medical decision-making, and represent an important force-protection role for EMS personnel at Base.
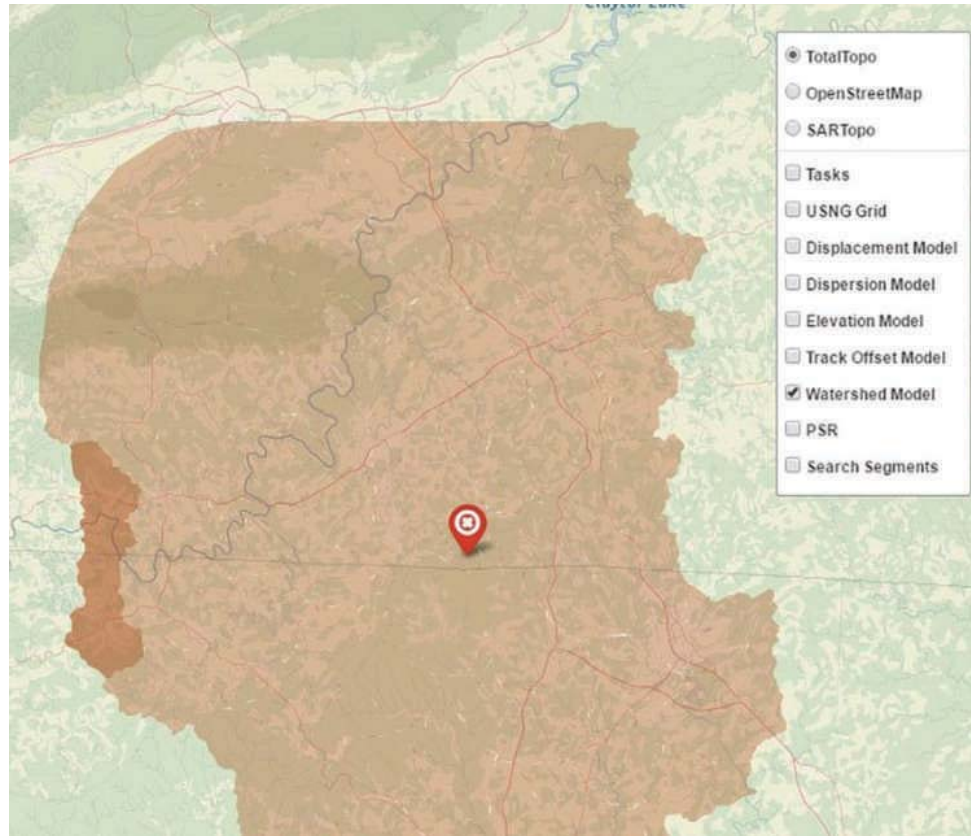
FIGURE 30.14. **FIND Watershed Model Map.** Based on statistics specific to the subject's profile, such as in Lost Person Behavior, this map displays the probability density based on the probability of the subject's being found in the same, adjacent, or beyond the adjacent watershed. Illustration by Robert Koester. Used with permission.

Force protection may also involve public health aspects at the team level between operations. This might involve screening team members for medical conditions that might cause problems in the field, and personal physical fitness evaluations, such as screening members for, supervising training for and testing members to the standard fire-service *work capacity test*[28]:

- **Arduous**: 3-mile level hike with 45-lb pack in 45 minutes
- **Moderate**: 2-mile level hike with 25-lb pack in 30 minutes
- **Light**: 1-mile level hike in 16 minutes.

While this work-capacity test of aerobic and walking fitness is designed for wildland firefighters, it has been adopted, as-is or slightly modified, in many disciplines. Some SAR teams have adopted alternative tests involving actual wildland trails with rough footing and elevation change.

RESCUE

Providing medical care during technical rescue, and during cave rescues, is covered in Chapters 24, 25, and 29.

But most wilderness rescues are **not** technical and **not** in a cave. Most wilderness rescue involves carrying a litter over terrain that varies from easy to difficult. In SAR we tend to talk of *evacuation* ("evac"), which is getting the patient from the incident site to the roadhead, whereas *transportation* is from the roadhead to the hospital. We generally categorize evacs as follows:

- **Nontechnical Evacs**: when ropes and technical rope-rescue hardware are not needed.
- **Semi-Technical Evacs**: when the terrain is steep enough to require a belay (safety rope) for the litter, but not for the litter bearers, though litter bearers may be clipped into the litter for additional security and to make the evacuation more efficient.
- **Technical Rescue**: when specialized vertical rescue techniques are needed, such as lowering a litter down a cliff, or raising it up a cliff. If it is not a cliff, but it is steep enough to need the same techniques, it is still technical rescue.

Most wilderness rescues are nontechnical evacs. A sizable minority are semi-tech evacs. A small fraction are true technical rescues. The distribution depends quite a lot where you are; for instance, in the Boundary Waters Canoe Area Wilderness, which includes the highest peak in Minnesota, Eagle Mountain (701 m [2,301 ft]), technical rescues are unlikely, while

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in Rocky Mountain National Park, where the road elevations vary between 2,350 m (about 7,800 ft) and 3,713 m (12,183 ft), technical rescues are more likely. Nonetheless, even in very rugged mountains, there tends to be plenty of what is often called "humping the litter down a trail."

Learning how to conduct nontechnical and semitechnical evacuations is beyond the scope of this chapter. However, for those wishing to learn, a free text on the topic is available online.[29]

There are a few things about nontechnical and semi-tech evacs specific to WEMS that you should know. First, position on the litter team. On level or fairly level ground, it is standard to have six litter bearers. And regardless of which direction you are headed, the usual standard is to have the litter handler in the front left (the "driver's seat," at least in the United States) be *the litter captain*. The litter captain gives instructions to the rest of the litter. If the litter must back up, then whoever's *now* in the front left is the litter captain. If it is a semi-tech evac, then the litter captain is also the one who communicates, on behalf of the entire litter team, with the rope/belay team.

There are good arguments that the top medical person on the team—referred to here as *the medic*—should not help carry the litter, but should just walk along with the litter all the time, as litter bearers get fatigued and rotate out of carrying the litter. That means the medic can continue to stay with the litter. This does not always work. Sometimes there is just no way to stay right with the litter without helping to carry it, especially in narrow cave passages or along a narrow trail. And, for that matter, there may not be enough litter bearers to spare the medic from having to help hump the litter. If the medic has to be on the litter, then the medic should be the one and only person who talks to the patient. Having six people chattering with the patient is confusing for the litter team and the medic, not to mention distressing unprofessional behavior from the patient's perspective.

Another standard, though not as standard as the litter captain, is that the litter bearer in the front right is the *speaker*. If the patient does not have much in the way of medical problems, let us just say a badly sprained ankle, then there is not much need for the medic to talk with the patient all that much. But it is still unprofessional to have everyone on the litter team chatting with the patient. So that person in "the shotgun seat," the front right, should be the speaker and the only one to be chatting with the patient unless the patient initiates a conversation with one of the other litter bearers.

One other issue with evacuations, even nontechnical ones, is of keeping medical records. This is discussed in more detail in Chapter 31. A detailed discussion of the issues around a field medical record, and a recommended record form, has been published by the ASRC.* The major conclusions were that electronic systems are not yet reliable, flexible, and hardy

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*http://archive.asrc.net/ASRC-Medical/2016-01-17-ASRC-Patient-Record-Form-1.0.pdf.

enough to replace paper, that water-resistant paper is a must, and two-part forms on water-resistant paper so that a copy can easily be handed off to during a transfer to another EMS service. Other considerations include:

- Small: Fits in a cargo pocket, big shirt pocket, or parka pocket.
- Big: big enough to reasonably write on.
- Light.
- Durable.
- Works in rain and snow.
- Should have mnemonics with it, either on the forms themselves or on a separate page, to help remind us how to do good medical charting.
- Should follow principles of good form design and good information design, as expressed in *Forms for People*[30] and the work of Yale's Edward Tufte.[31–35]
- Suitable for adding additional reference pages for not only medical reference material, but also generic SAR references.

References

1. Phillips K, Longden MJ, Vandergraff B, et al. Wilderness search strategy and tactics. *Wilderness Environ Med*. 2014; 25(2):166-176.
2. Heggie TW, Heggie TM. Search and rescue trends associated with recreational travel in US national parks. *J Travel Med*. 2009; 16(1):23-27.
3. National Search and Rescue Committee (U.S.). *Land Search and Rescue Addendum to the National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual*. Charlottesville, VA: dbS Productions; 2012.
4. Young CS, Wehbring J. *Urban Search: Managing Missing Person Searches in the Urban Environment*. Charlottesville, VA: dbS Productions; 2007.
5. Koester RJ, Cooper DC, Frost J, Robe R. Sweep width estimation for ground search and rescue. DTIC Document; 2004. Available at http://www.dtic.mil/dtic/tr/fulltext/u2/a511593.pdf. Accessed August 17, 2017.
6. Cooper D, Frost J, Robe RQ. Compatibility of land SAR procedures with search theory. DTIC Document; 2003.
7. Chiacchia KB, Houlahan HE. Effectors of visual search efficacy on the Allegheny Plateau. *Wilderness Environ Med*. 2010; 21(3):188-201.
8. Koester RJ, Chiacchia KB, Twardy CR, Cooper DC, Frost JR, Robe RQ. Use of the visual range of detection to estimate effective sweep width for land search and rescue based on 10 detection experiments in North America. *Wilderness Environ Med*. 2014;25(2):132-142.
9. Robe RQ, Frost J. A method for determining effective sweep widths for land searches. Procedures for conducting detection experiments. DTIC Document; 2002.
10. Frost J. The theory of search: a simplified explanation. Report by Soza & Company Ltd and Office of Search and Rescue US Coast Guard; 1998.
11. Stoffel R, Swombow C, Andrew T, International ER, Jones ASG. *The Handbook for Managing Land Search Operations*. Cashmere, WA: Emergency Response International; 2001.
12. Koester RJ. *Lost Person Behavior: A Search and Rescue Guide on Where to Look for Land, Air, and Water*. Charlottesville, VA: dbS Productions; 2008.

13. Mattson RJ. *Establishing Search Priorities. Search Theory and Applications*. Berlin, Germany: Springer; 1980:93-97.

14. Roarty H, Glenn S, Allen A. Evaluation of environmental data for search and rescue. In: *Oceans 2016*. Shanghai: IEEE; 2016:1-3.

15. Cooper A. *The Inmates are Running the Asylum*. Indianapolis, IN: Sams; 1999.

16. Twardy C. Incoherence & Mattson. SARBayes: Bayesian Methods for WiSAR. Available at http://sarbayes.org/search-theory/incoherence-mattson/. Accessed August 17, 2017.

17. Karvetski CW, Olson KC, Mandel DR, Twardy CR. Probabilistic coherence weighting for optimizing expert forecasts. *Decis Anal*. 2013; 10(4):305-326.

18. Cornell EH, Heth CD, Kneubuhler Y, Sehgal S. Serial position effects in children's route reversal errors: Implications for police search operations. *Appl Cogn Psychol*. 1996;10(4):301-326.

19. Colwell M. Trail-based probability of area: a terrain-based approach to POA estimation. SAR Technology, 1997. Available at http://sartechnology.ca/sartechnology/ST_TrailPOA.htm. Accessed August 19, 2017.

20. Koopman BO. A theoretical basis for method of search and screening. DTIC Document; 1946.

21. Koopman BO. Search and Screening: General Principles with Historical Applications. New York, NY: Pergamon Press; 1980.

22. Surowiecki J. *The Wisdom of Crowds: Why the many are Smarter than the few and How Collective Wisdom Shapes Business, Economies, Societies, and Nations*. New York, NY: Doubleday; 2004.

23. Koester RJ, Gordon R, Wells T, Tucker R. Auditory and light based two-way effective sweep width for responsive search subjects in New Zealand mountainous terrain; 2013:1. Available at: www journalofsar org. Accessed July 1, 2017.

24. Koester RJ. *Incident Command System Field Operations Guide for Search and Rescue (ICS FOGSAR)*. Charlottesville, VA: dbS Productions; 2014.

25. FEMA. National Incident Management System (NIMS) Incident Command System (ICS) Forms Booklet, FEMA 502-2; 2010. Available at https://www.fema.gov/media-library-data/20130726-1922-25045-7047/ics_forms_12_7_10.pdf. Accessed August 19, 2017.

26. Rose C. Mapping Technology in Wilderness Search and Rescue. University of Wisconsin—Madison; 2015.

27. Koester RJ, Greatbatch I. Missing aircraft crash sites and spatial relationships to the last radar fix. *Aerosp Med Hum Perform*. 2016;87(2):114-121.

28. Sharkey B, Technology USFS, Program D. Work Capacity Tests for Wildland Firefighters: Test Administrator's Guide. USDA Forest Service, Technology and Development Center; 1998.

29. Conover K. Nontechnical and Semi-tech Evacs. Search and Rescue Topics. May 2014. Available at http://www.conovers.org/ftp/SAR-Evacs.pdf. Accessed August 19, 2017.

30. Barnett R. *Forms for People: Designing Forms that People Can Use*. Canberra, Australia: Robert Barnett and Associates Pvt. Ltd; 2005.

31. Tufte ER. *Envisioning Information*. Cheshire, CT: Graphics Press; 1990.

32. Tufte ER. *Visual Explanations: Images and Quantities, Evidence and Narrative*. Cheshire, CN: Graphics Press; 1997.

33. Tufte ER. *The Visual Display of Quantitative Information*. Cheshire, CN: Graphics Press; 2001.

34. Tufte ER. *The Cognitive Style of PowerPoint: Pitching out Corrupts Within*. Cheshire, CN: Graphics Press; 2006.

35. Tufte ER. *Beautiful Evidence*. Cheshire, CN: Graphics Press; 2006.

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Network Analysis for Search Areas in WiSAR Operation

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Network analysis for search areas in WiSAR operations

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Abstract

Purpose – A search and rescue incident is ultimately all about the location of the missing person; hence, geotechnical tools are critical in providing assistance to search planners. One critical role of Geographic Information Systems (GISs) is to define the boundaries that define the search area. The literature mostly focuses on ring- and area-based methods but lacks a linear/network approach. The purpose of this paper is to present a novel network approach that will benefit search planners by saving time, requires less data layers and provides better results.

Design/methodology/approach – The paper compares two existing models (Ring Model, Travel Time Cost Surface Model (TTCSM)) against a new network model (Travel Time Network Model) by using a case study from a mountainous area in Austria. Newest data from the International Search and Rescue Incident Database are used for all three models. Advantages and disadvantages of each model are evaluated.

Findings – Network analyses offer a fruitful alternative to the Ring Model and the TTCSM for estimating search areas, especially for regions with comprehensive trail/road networks. Furthermore, only few basic data are needed for quick calculation.

Practical implications – The paper supports GIS network analyses for wildland search and rescue operations to raise the survival chances of missing persons due to optimizing search area estimation.

Originality/value – The paper demonstrates the value of the novel network approach, which requires fewer GIS layers and less time to generate a solution. Furthermore, the paper provides a comparison between all three potential models.

Keywords GIS, Network analysis, WiSAR

Paper type Research paper

1. Introduction

In the European Alps, particularly in tourist areas, many hiking trails allow unlimited access to the mountains, almost regardless of visitors' hiking skills. In Austria, about 400 people annually are reported missing in the mountains and have to be taken back to safety (OEBRD – Austrian Mountain Rescue Organization, 2013). If the location of a missing person is unknown, an extensive search operation is necessary first. In the preparation and planning process of these operations, Geographic Information Systems (GISs) are increasingly used to assist the management and analysis of spatial data, providing support to the search and rescue (SAR) team. Critical in this process is the estimation of the search area size, affecting the time necessary to cover the area during the search. A more accurately search area results in more efficient SAR operations with increasing chance of survival for the person missing. Therefore, different geospatial methods were developed – mostly

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focusing on area-based approaches. The aim of this paper is twofold: first, to present a network-based GIS approach using roads and trails, in this paper defined as Travel Time Network Model (T2Net). Second, to compare strengths and weaknesses to create a probability of area (POA) map with the two most common methods, Ring Model and Travel Time Cost Surface Model (TTCSM). The metric used to compare the three models is the preparation time factor, required data, analytical techniques involved and the probability density (Pden).

2. SAR in mountainous areas – related work

SAR operations are emergency situations where trained experts help a person in distress. An operation includes two stages, which can significantly differ due to the situation and which are not necessarily carried out simultaneously. First, the person has to be located. In the rescuing phase, the person has to be brought back to safety and provided with medical care (Cooper, 2005).

Operations in largely unpopulated areas with minimal access to infrastructure are referred to as wilderness or wildland search and rescue (WiSAR), including missions in mountainous areas. If access to shelter or medical care is missing, WiSAR operations can also occur in urban areas, e.g. after natural disasters (Durkee and Glynn-Linaris, 2012). SAR teams in Austria are based on rescue and relief organizations (firefighters, mountain rescue and Red Cross), in the mountains WiSAR operations are carried out by specialized mountain rescue teams and alpine police units (SARUV Austria, 2016). According to the 2013 annual report of the Austrian Mountain Rescue Organization, over 7,000 operations took place (five-year average 6,745 operations), with approximately 400 searches annually (OEBRD – Austrian Mountain Rescue Organization, 2013). Despite this high number, no database for these operations is available.

Four steps characterize SAR procedures: locate – access – stabilize – transport. From a geo-analytical perspective, each step is representing a separate spatial problem (Wysokinski *et al.*, 2014). The locate and access phases are critically important regarding time and space (Winter and Yin, 2010) – a limited number of task forces must find a person as soon as possible within a correspondingly large area, since the chance to survive drops with increasing time (Doherty *et al.*, 2014). An analytical measurement for finding a person is the probability of success (POS), which is calculated based on the POA and the probability of detection (POD) (Koopman, 1999):

$$POS = POA \times POD$$

To increase POS, different methods are feasible, e.g. to increase POD by using a higher number of emergency teams and/or better sensors and tactics to increase the POD for each team, or to reduce the search area by improving the estimation of the POA (Cooper *et al.*, 2003). Due to limitations in work force and difficulties to influence the POD, Doherty *et al.* (2014) suggested to optimize the search area. Another metric is the Pden, which is calculated as the probability per search size (Sava *et al.*, 2016).

3. GIS for SAR – underlying considerations

3.1 Potentials of GIS

To analyze spatial problems and manage large amounts of data, both before and during SAR operations, GIS offers numerous possibilities (Ferguson, 2008). As investigated by Tomaszewski (2015) for disaster relief issues, GIS works as a tool for organization and administration (Environmental Systems Research Institute, 2010, 2013). Maps as one basic result of GIS analyses are used in the briefing process of task forces and in the field during an operation. However, it is useful to prepare spatially referenced data in advance of a SAR

operation to make it quickly available in case of emergency. Information about roads/streets, waterways, elevation, land cover and aerial photography has to be compiled. Information about the current situation needs to be collected by interviews and observations. Next to personal notes, this includes weather forecasts and operation-related data like availability of equipment, people and/or vehicles. Moreover, the application of GIS for SAR needs high expertise in spatial data analytics (Tomaszewski, 2015). Therefore, members of SAR teams, employees of National Parks and computer specialists developed an extension of ArcGIS called MapSAR, enabling efficient management of information and the creation of maps using pre-defined templates. Generating maps with MapSAR is easy, no or basic GIS knowledge is needed. If additional spatial analyses are required in the WiSAR operation, GIS expertise is needed, causing limitations for further implementation. Many approaches are limited to scientific publications, dealing with geostatistical and geotechnical assessment of search areas (Doherty *et al.*, 2014), modeling behaviors of missing persons (Koester, 2008; Lin and Goodrich, 2010; Sava *et al.*, 2016) and planning issues integrating heterogeneous agents (Flushing *et al.*, 2012). The common goal is to provide methods for better organization, quick and successful completion of SAR operations. To make advanced GIS analyses available for the SAR teams despite lacking GIS knowledge, analytical processes can be automated and only results are provided to the teams (Wysokinski *et al.*, 2014).

3.2 GIS network analysis for SAR analysis
The term network is used in numerous fields of science for modeling, and although the underlying concepts vary essentially (Nyerges *et al.*, 2011). In this paper, network is defined as a collection of linear features, roads and trails, where nodes represent intersections and edges represent the paths between intersections (Popovich *et al.*, 2009).

Although network analysis carries a huge potential for WiSAR they are yet rarely applied. Reasons for this are road/trail network density – few linear objects in areas cannot provide meaningful results – the availability of vector data, and different locational conditions worldwide, e.g. US National Parks vs European Alps. Theodore (2009) implemented an application for the search of missing hikers in Yosemite National Park, including 3D and spatial analyses. He applied network analysis primarily for splitting up the search area.

Canadian researchers provided network analysis methods for locating persons with Alzheimer. They combined geotechnical applications, statistical analyses of recent cases and medical knowledge with subject-related information about the patients (Croteau and Belhassine, 2016). Based on a road network, the application provides routes and probabilities of decisions of disoriented patients at intersections including behavioral profiles. The results are presented as probability maps. This integrative application provides a suitable network-based approach in urban areas.

3.3 Data for SAR – precondition and challenge
The acquisition of current, accurate (geo-)data poses a major challenge in projects with geospatial scope. Missing data or data errors can produce misleading results, which may lead to injuries or loss of life. Additionally, data acquisition plays an important role since most SAR teams are nonprofit organizations in Europe. At its best geo-data sets are freely available as governmental or open source services. However, volunteered geographic information covers wider areas to various degrees of detail, completeness and accuracy. Additionally there is the need for situational data as spatial and/or qualitative data.

Statistical data from previous incidents form the basis of defining search areas for all three models. Unfortunately, many localities neglect to collect incident data. The International Search and Rescue Incident Database (ISRID) collects data and organizes

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the data to control for subject category, ecoregions, terrain and population density in the reported summary data (Koester, 2008). The algorithm that defines subject categories was further refined in 2010 (Koester, 2010). Additional data were collected increasing the database from 50,692 to 143,951 incidents in 2016. This is the new summary data (Table I) used to test the three models. A more detailed description of data requirements, adaptations, implementation and analysis is discussed in Section 4.

4. Three models, three probability maps

A practical example illustrates differences, pros and cons of three models: the Ring Model, the TTCSM and the T2Net. The models are described and calculated for an Austrian mountainous region, showing a high density of roads/trails with unrestricted access to the area. Next to probability maps (Figure 1), the Pden is used to compare the results and evaluate the results of the T2Net (Table II).

The study area, located in the Austrian province of Vorarlberg, is covering an area of 414 km^2, accessible by 1,234 km of roads and 1,138 km of trails. The northwestern part, the Rhine Valley (elevation 400 m), is an urban region, while the remaining areas are mountainous with an elevation up to 2,095 m. The IPP is set along the European long distance trail E4 (Figure 1(a)). Statistical data used to evaluate the three models were taken from ISRID2.0 due to a lack of data from Austrian sources. The methodology of collecting and cleaning the data is identical to the first creation of ISRID, previously described (Koester, 2008). The data were filtered for search incidents only, hikers only, temperate eco domain only, wilderness or rural population density, mountainous terrain only, excluding investigative outcomes, and containing data in either hours of mobility or beeline distance from the IPP.

4.1 Ring Model

The Ring Model using beeline distance is only based on statistical data (Doherty *et al.*, 2014, S. 102; Koester, 2008); no additional spatial information is integrated. Search areas are indicated as concentric circles around the IPP using the distance a hiker can be found with a certain probability as radius. These distances define the probability areas around the IPP and are calculated with GIS multiple-ring buffer analysis, but can simply be obtained with paper and pencil (Table I).

Data sets and tools	Ring Model	TTCSM	T2Net
Geospatial data			
Starting point – IPP	X	X	X
Roads		X	
Paths		X	X
Flowing water bodies		X	
Stagnant water bodies		X	
Digital Elevation Model		X	X
Land-cover classification		X	
Additional data			
Situational data	X	X	X
Statistical data	X	X	X
Tool	Paper and pencil or GIS multiple-ring buffer	GIS raster analysis (raster calculator)	GIS network analysis (service area and routing)

Sources: Adapted from Doherty *et al.* (2014) and Frakes *et al.* (2014)

Table I.
Basic data and tools for the Ring Model, TTCSM and T2Net

Legend

⊗ IPP   POA

— Roads   10%

— Paths   20%

30%   60%   90%

40%   70%

50%   80%

Kilometers
0 1 2   4   6   8   10

N

Sources: Koester (2010), VoGIS (2016), Software: ArcGIS 10.5

In total, 1,154 evaluated search operations of ISRID2.0 lead to the following probabilities at 10 percent level (Table II) and are visualized in a probability map (Figure 1(b)). The results indicate that the search area approximately doubles with each 10 percent increase of probability. A missing hiker is found with a probability of 50 percent in a distance of 2.4 km from IPP, which is equal to an area of 18 km^2. Searching the 100 percent probability zone requires covering almost 30 times the study area (11,575 km^2). Since the probability area is not integrating terrain in the model, Figure 1(b)

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shows that some parts of that area will be difficult or impossible to cover well. The Pden shows higher values compared to the TTCSM and T2Net especially at the 10 percent level (Table II).

4.2 TTCSM
The National Park Service of the US Department of Interior (Frakes *et al.*, 2014) developed the TTCSM, also called mobility model, which uses raster data. It is based on the mobility time, indicating how long a person is moving away from the IPP, and visualized in a speed raster. In contrast to the Ring Model, information about terrain and vegetation is implemented as impedance raster (Doherty *et al.*, 2014). This corresponds to a cost-distance approach, calculating the lowest accumulated cost-distance from each cell to the IPP. An algorithm minimizes the total costs based on a speed and resistance grid (Adriansen *et al.*, 2003).

The speed grid uses Tobler's (1993) Hiking Function to integrate the slope and exclude steep areas (> 40°) (Doherty *et al.*, 2014). Grid cells with roads can additionally be weighted with the maximum driving speed (Frakes *et al.*, 2014). Imhof (1950) presumed the speed of a person moving off-roads with 60 percent of the average speed.

The calculation of the resistance grid for the Austrian example involves the following steps:

- An impedance of 0 percent is assigned to grid cells, which are classified as roads/trails.

- An impedance of 100 percent is assigned to non-traversable grid cells (e.g. stagnant water bodies).

- Grid cells of streaming water bodies require a detailed observation and are classified based on Strahler's stream order methodology (Frakes *et al.*, 2014; Strahler, 1952); the impedance increases with the rank of the stream. Water bodies are easier to cross close to their spring than downstream (adopted from Doherty *et al.*, 2014).

- If roads are missing, people need to move cross-country (Frakes *et al.*, 2014). Depending on the land cover, different resistances can be expected and are integrated from CORINE land-cover classification (100×100 m resolution) (European Environment Agency, 1995).

Based on the speed and resistance raster the cost surface is calculated, incorporating the maximum speed per cell. Statistical data of ISRID2.0, the mobility time, are added to the model. Koester (2008) estimated that a missing person is generally 1 hour moving away from IPP with a probability of 25 percent, 5 hours with 50 percent, 10 hours with 75 percent

POA (%)	Distance from IPP (km)	Mobility time (hours)	Ring Model Area (km²)	Pden	TTCSM Area (km²)	Pden	T2Net Area (km²)	Pden
10	0.1	0	0.03	3.18310	0	0.00	0	0.00000
20	0.6	1	1.13	0.09095	1.37	0.07300	1.41	0.07092
30	1.1	2	3.80	0.03745	7.07	0.01754	7.17	0.01736
40	1.6	4	8.04	0.02358	31.94	0.00402	36.37	0.00342
50	2.4	5	18.10	0.00995	59.36	0.00365	68.48	0.00311
60	3.2	7	32.17	0.00710	135.52	0.00131	175.48	0.00093
70	4.5	8	63.62	0.00318	190.18	0.00183	263.78	0.00113
80	6.2	12	120.76	0.00175	397.93	0.00048	474.46	0.00047
90	10.0	17	314.16	0.00052	na	na	na	na

Table II.
Distance and hiking hours gathered from ISRID to calculate probability areas and Pden of the Ring Model, TTCSM and T2Net

and 24 hours with 95 percent. The resulting raster can show gaps, e.g. for pixels in inaccessible areas, therefore it is converted to vector polygons, and generalized afterwards.

Compared to the Ring Model, the TTCSM provides results starting with the 20 percent probability area, since at lower probability persons are moving zero hours away from IPP. For the study area, probability areas higher than 90 percent cannot be calculated. The resulting polygons extend the search area and trail data for these areas (Switzerland and Germany) are not available. The Pden shows lower values for the TTCSM than for the Ring Model, dropping quickly after 50 percent (Table II). A missing hiker is found with a probability of 50 percent moving 5 hours away from IPP, which is equal to an area of 59 km^2, which is three times the area of the Ring Model at the given probability (Figure 1(c)).

4.3 T2Net – an alternative approach to support SAR operations

Determining a search area based on linear objects utilizes GIS network analyses. The network includes vector-based data sets of roads/trails, a Digital Elevation Model (DEM) and statistical data. The main impedance factor is the mobility time.

The probability area results as polygon stretched along the roads/trails according to the time moving away from IPP. Additionally, different modes of transportation can be taken into account. If transport infrastructure is available, a person also might use motorized vehicles. The impedance for the road network can be calculated with the maximum speed. One-way streets have to be considered as well as elevation changes along the roads. Speed in the trail network is based on Tobler's Hiking Function, assuming a speed of 5.0 km/h in flat terrain. Hiking uphill or downhill is resulting in different hiking speed (Irtenkauf, 2014). Similar to the TTCSM, slopes more than 40° are excluded (Frakes *et al.*, 2014).

The first step in the T2Net is to prepare the underlying network. Here, it is crucial to define an appropriate graph, ensuring positional accuracy of network elements and connectivity. Network errors and/or gaps will result in a failure of the algorithm. Following steps are integrated:

- Linear features are split in 5 m edges according to the 5×5 m slope raster, to ensure a more exact modeling process.

- Elevation of the DEM is assigned to each node. Based on this information, the increase or decrease of elevation is calculated depending on the direction of digitalization and assigned to each edge.

- Using Tobler's Hiking Function, the hiking speed is calculated in and against direction of digitalization.

- If a multimodal approach is chosen, the driving speed is assigned to the road edges.

- Inverting and scaling the result to gather hours per length of edge.

- This gives the amount of time necessary to traverse an edge.

The network data set is generated using hours as impedance/cost factor. The polygons indicating the probability areas are calculated using the service area tool (ArcGIS 10.5) at defined threshold values. Threshold values are mobility times of ISRID2.0. To generate comparable results with the TTCSM, the multimodal approach was not used for the case study. Positions at the intersections of the network and the borders of probability polygons are time accurate according to the mobility time of ISRID.

The generated network supports various analyses in the context of SAR operations. Predominantly two operations can be applied: first, in case of an unknown position of a person, the search area can be visualized using the service area tool. Second, knowing the location of the person, the quickest/easiest/shortest route to this location can be calculated.

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Figure 1(d) illustrates the T2Net using ISRID2.0 statistical data. Hiking times between 0 and 24 hours determine the probability areas at 10 percent steps. For the study area, ISRID data show that 50 percent of all missing hikers were found within $68 \, km^2$ from IPP, including 261.34 km trails/roads. Comparing the Pden of the T2Net with the TTCSM presents slightly lower values. The map (Figure 1(d)) shows that the probability areas match the linear features. Especially along the ridge from SW to NE with smooth terrain, an extension of the polygons can be observed.

5. Discussion – pros and cons

The main goal of this paper is to present the T2Net as additional model to calculate search areas for SAR operations. The T2Net is compared with two widely used models, the Ring Model and the TTCSM, to analyze advantages and disadvantages. The results are summarized in Tables II and III.

While the Ring Model does not consider other than different data for mountainous vs non-mountainous terrain or additional information, the TTCSM based on an area approach and the T2Net with a linear basis integrate various additional criteria (see Table I). In contrast to the Ring Model and the TTCSM, the basis of the T2Net is a network of roads and trails. Therefore, the model is suitable for areas where a dense road/trail network is available as well as for small-scaled areas with high relief energy, since it differentiates between hiking up- and downhill. The vector-based data set using linear features can be seen as advantage, since Koester (2008) stated that more than 50 percent of missing hikers are found along road/trail or other linear features, and here 95 percent are located within a distance of 424 m of the linear elements.

The T2Net offers advantages in respect to data, analytical steps and results. The model uses vector data, representing roads/trails and integrates GIS network analysis. One bottleneck of the T2Net is the availability of vector data for trails.

In all three models, the implementation of statistical data is crucial. While statistical data are used to refine the search area, situational data can lead to more exact results, although hard to gather. In the TTCSM, sources of inaccuracies can be named as the low resolution of CORINE land-cover classification, resistance values defined by Sherrill *et al.* (2010) and

	Ring Model	TTCSM	T2Net
Advantages	Easy analysis Cheap and fast No additional information necessary	Movement cross-country included Walking speed included Barriers included Not accessible/traversable areas excluded Detailed result in cross-country areas	Multimodal network possible Few layers Detailed polygon Fast calculation of search areas compared to TTCSM Determination of walking speed according to up- or downhill movement SAR teams can use routing tool for wayfinding to located person (Vector) data on roads/trails necessary
Disadvantages	No additional information (terrain, vegetation) included No linear features (street/trails) included	Many information layers necessary Resulting polygons can include gaps Equal walking speed regardless of walking up- or downhill Resolution depending on input data	

Table III.
Advantages and disadvantages of the Ring Model, TTCSM and T2Net

flowing water bodies. The Strahler number, for example, does not take seasonal variations of the runoff into account. Modeling the behavior of a person based on statistical data does not consider the critical characteristics of the unique individual. In addition, the distance from the IPP and dispersion angle models does not take the unique characteristics of the terrain into full consideration. The challenge in applying GIS-based models is, next to the modeling process itself, to overcome the gap between an individualized simulation and a too generalized approach.

T2Net involves a fewer number of data sets, but leads to similar results like the TTCSM as the Pden and the map indicate. If the network data set is prepared in advance, in case of emergency only one analytical step – the calculation of the service area – generates the probability area map. The TTCSM involves several analytical steps calculating the probability area, which affords GIS knowledge and time. Since the time is essential for the chance of survival simple, quick methods are preferred.

The walking speed calculated for the T2Net was furthermore evaluated with hiking times provided by the provincial government of Vorarlberg (VoGIS, 2016). The hiking times in VoGIS were conducted in the field through measurement. The comparison of the walking speed calculated with T2Net with the VoGIS data resulted in a variation of ± 10 percent. This indicates that the hiking speed derived with the T2Net shows an appropriate results regarding the hiking time.

Finally, the comparison of Pden for the TTCSM and the T2Net shows related results, although the Pden for the T2Net is slightly higher and the Ring Model provides best results.

From a practical perspective, an additional advantage of the T2Net can be seen in the network analysis itself. Similar to a car navigation system the SAR teams can use routing algorithms to calculate routes depending on different impedances, e.g. the quickest or shortest route to the person located. This opens new fields of application, e.g. in case of a hiker's accident, in case of barriers through landslides, avalanches, etc.

6. Conclusion and further research

The paper presents an alternative approach to define search areas, the T2Net. It compares it with two common models, differing in terms of complexity, data and accuracy. While controlling for the same source of data the Ring Model scores in terms of time, costs and simplicity, TTCSM and T2Net integrate the specification of terrain due to the integration of geo-data. In the TTCSM, large amounts of data lead to time-, cost- and knowledge-intensive analyses, and may result in limited success since time is a critical factor in locating a missing hiker. T2Net methods offer a viable approach, since detailed results are obtained with a comparatively small number of geo-data and a short preparation and calculation time, in case road/trail data are available. They should be preferred, if the region shows a compact network of roads/trails.

One critical issue to generate an appropriate search area is the availability, amount and accuracy of geo and statistical data. As statistical data ISRID, an international statistical data set is integrated into the calculation. Future efforts can be made in combining international with local and open source data, and data mining through SAR teams. One future research issue can be seen in testing the T2Net with local data and compare it with ISRID results.

The integration of elevation changes from IPP or scattering angles of movement along the path will be additional research issues. In terms of GIS analyses, advanced geotechnical modeling algorithms and partly automated computation of search areas are of special interest.

Compared to North America, GIS-based WiSAR operations are not well established in Europe yet. Reasons for this are the lack of data, missing GIS knowledge of rescue teams and different regional settings (small-scaled, dense trail networks). However, the

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development of new WiSAR approaches should integrate experience of SAR teams and usability should guide the use of theoretical/scientific models. Therefore, extended evaluation of the TTNW with local data has to follow and proof the model in real world scenarios. To cope with the problem of cross-validating results in smaller areas, a more formal metric should be applied, e.g. MapScore (Sava *et al.*, 2016). This will allow calculating statistical parameters in order to compare the models on a more formal level.

References

Adriansen, F., Chardon, J.P., De Blust, G., Swinnen, E., Villalba, S., Gulinck, H. and Matthysen, E. (2003), "The application of 'least-cost' modelling as a functional landscape model", *Landscape and Urban Planning*, Vol. 64 No. 4, pp. 233-247.

Cooper, D.C. (Ed.) (2005), *Fundamentals of Search and Rescue*, Jones & Bartlett, Sudbury and National Association for Search & Rescue, Centerville, VA.

Cooper, D.C., Frost, J.R. and Robe, Q.R. (2003), *Compatibility of Land SAR Procedures with Search Theory*, US Department of Homeland Security, United States Cost Guard, Washington, DC.

Croteau, A. and Belhassine, K. (2016), "Geomatic SAR analytics", *FrontLine Security*, Vol. 11 No. 1, pp. 31-33.

Doherty, P.J., Guo, Q., Doke, J. and Ferguson, D. (2014), "An analysis of probability of area techniques for missing persons in Yosemite National Park", *Applied Geography*, Vol. 47 No. 2, pp. 99-110.

Durkee, G. and Glynn-Linaris, V. (2012), "Using GIS for wildland search and rescue", ESRI, Redlands, CA.

Environmental Systems Research Institute (2010), "GIS joins search for a missing hiker on California's Mount Whitney", available at: www.esri.com/news/arcwatch/0410/feature.html (accessed November 2, 2015).

Environmental Systems Research Institute (2013), "Disaster technology could help find lost hikers in Australia", available at: https://esriaustralia.com.au/news/disaster-technology-could-help-find-lost-hikers-in-australia-nar-185 (accessed November 2, 2015).

European Environment Agency (1995), "Corine Land Cover", available at: www.eea.europa.eu/publications/COR0-landcover (accessed March 5, 2016).

Ferguson, D. (2008), "GIS for wilderness search and rescue", paper presented at the ESRI Federal User Conference, Washington, DC, February 20-22, available at: http://sierranaturenotes.com/GI$/Docs/Literature/Ferguson_2008_GISforWildernessSearchandRescue.pdf (accessed November 2, 2015).

Flushing, E.F., Gambardella, L. and Di Caro, G.A. (2012), "GIS-based mission support systems for wilderness search and rescue with heterogeneous agents", *Proceedings of the 2nd Workshop on Robots and Sensors Integration in Future Rescue Information System (ROSIN), Vilamoura, Algarve (Portugal), October 11*, available at: www.researchgate.net/publication/260247452_GIS-based_mission_support_system_for_wilderness_search_and_rescue_with_heterogeneous_agents (accessed March 13, 2016).

Frakes, B., Sherrill, K.R. and Flowe, T. (2014), "National Park Service Travel Time Cost Surface Model (TTCSM): user guide", Vol. 838, Natural Resource Report NPS/NRSS/NRR, NPS, Fort Collins, CO.

Imhof, E. (1950), *Gelände und Karte*, Eugen Rentsch Verlag, Zürich.

Irtenkauf, E. (2014), "Analyzing Tobler's Hiking Function and Naismith's Rule using Crowd-Sourced GPS Data", working paper, The Pennsylvania State University, University Park, PA, available at: https%3A%2F%2Fgis.e-education.psu.edu%2Fsites%2Fdefault%2Ffiles%2Fcapstone%2FIrtenkauf_596B_20140430.docx&usg=AFQjCNF2PxsxqmxjtzkAfcAO35zhnGty3g&sig2=_6H6mfC9ACCcYKvOSzwaHg&bvm=bv.143423383,d.d24 (accessed March 13, 2016).

Koester, R.J. (2008), *Lost Person Behavior: A Search and Rescue Guide on Where to Look – for Land, Air and Water*, dbS Productions, Charlottesville, VA.

Koester, R.J. (2010), *Lost Person Behavior Instructor Activity Guide*, dbS Productions, Charlottesville, VA.

Koopman, B. (1999), *Search and Screening, General Principles with Historical Applications*, rev. ed., Military Operations Research Society, Arlington, VA.

Lin, L. and Goodrich, M.A. (2010), "A Bayesian approach to modeling lost person behaviors based on terrain features in wilderness search and rescue", in Carley, K.M. and Frantz, T.L. (Eds), *Computational and Mathematical Organization Theory*, Springer Verlag, Berlin and Heidelberg, pp. 300-323.

Nyerges, T.L., Couclelis, H. and McMaster, R. (2011), *The SAGE Handbook of GIS and Society*, Sage, Los Angeles, CA, London, New Delhi, Singapore and Washington, DC.

OEBRD – Austrian Mountain Rescue Organization (2013), "Annual report", OEBRD, Klagenfurt.

Popovich, V.V., Schrenk, M., Claramont, C. and Korolenko, K.V. (2009), *Information Fusion and Geographic Information Systems, Proceedings of the Fourth International Workshop in St Petersburg 2009*, Springer-Verlag, Berlin and Heidelberg.

SARUV Austria (2016), "Über uns", available at: www.saruv.at/ueber-uns (accessed February 11, 2016).

Sava, E., Twardy, C., Koester, R. and Sonwalkar, M. (2016), "Evaluating lost person behavior models", *Transactions in GIS*, Vol. 20 No. 1, pp. 38-53.

Sherrill, K.R., Frakes, B. and Schupbach, S. (2010), "Travel Time Cost Surface Model: Standard Operating Procedure", Vol. 238, Natural Resource Report NPS/NRPC/IMD/NRR, National Park Service, Fort Collins, CO.

Strahler, A.N. (1952), "Hypsometric (Area-Altitude) analysis of erosional topography", *Geological Society of America Bulletin*, Vol. 63 No. 11, pp. 1117-1142.

Theodore, J. (2009), "Yosemite uses GIS for coordinating search and rescue operations", ArcUser, Summer, pp. 66-69.

Tobler, W. (1993), "Three presentations on geographical analysis and modeling: non-isotropic modeling speculations on the geometry of geography global spatial analysis", available at: www.ncgia.ucsb.edu/Publications/Tech_Reports/93/93-1.PDF (accessed February 11, 2016).

Tomaszewski, B. (2015), *Geographical Information Systems (GIS) for Disaster Management*, CRC Press, Boca Raton, FL, London and New York, NY.

VoGIS (2016), "Geodata of the Province Vorarlberg, Austria", available at: http://vogis.cnv.at/geodaten (accessed November 2, 2015).

Winter, S. and Yin, Z.-C. (2010), "Directed movements in probabilistic time geography", *International Journal of Geographical Information Science*, Vol. 24 No. 9, pp. 1349-1365.

Wysokinski, M., Marcjan, R. and Dajda, J. (2014), "Decision support software for search & rescue operations", *Procedia Computer Science*, Vol. 35, pp. 776-785.

Further reading

MapSAR (2016), "GIS for wildland search and rescue", available at: www.mapsar.net/ (accessed February 15, 2016).

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Sweep Width Estimation for Ground Search and Rescue

Koester, R.J., Cooper, D.C., Frost, J.R., & Robe, R.Q
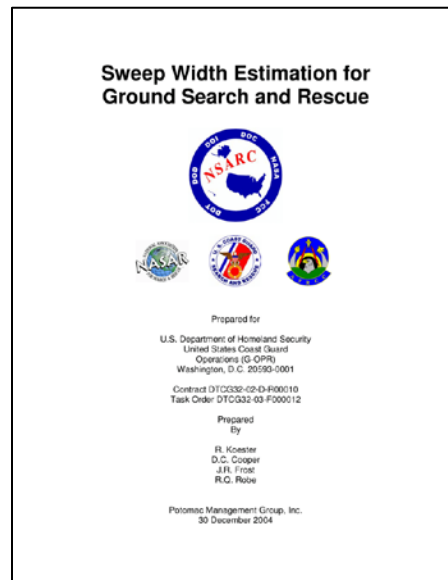
Bound Separately

U.S. Department of Homeland Security

United States Coast Guard Operations (G-OPR)

Washington, D.C.

2004

Auditory and Light Based Two-Way Effective Sweep Width for Responsive Search Subjects in New Zealand Mountainous Terrain

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Auditory and Light Based Two-Way Effective Sweep Width for Responsive Search Subjects in New Zealand Mountainous Terrain

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Abstract

Search theory is completely dependent upon an accurate assessment of how well a search area was covered by a team or the Probability of Detection (POD). Determining the POD for auditory whistle blasts and a response to sighting lights at night (sound-light line technique) involves a two-way detection problem.

Two experiments were carried out at Nelson Lakes along the Porika Road track in New Zealand. The first experiment was conducted during the day with six subjects and fourteen two-person teams conducting a sound line tactic. The detection index for a search team hearing a shout was 332 meters. The detection index for a subject hearing a whistle was 401 meters. Searchers were able to detect 99% of high-visibility clues (orange gloves) and 52% of low-visibility clues (gray gloves) on the track. The night experiment was conducted at the same location, but with different search subjects placed in different locations. Search teams used a sound-light line tactic in two-person teams. The detection index for a search team hearing a shout was 306 meters. The detection index for a subject hearing a whistle was 395 meters and seeing a light 277 meters. The detection index for a subject detecting either signal was 460 meters.

This is the first report in the land search literature of both elements (searcher and subject) of a two-way detection problem.

Keywords: Detection index, Sweep Width, two-way detection, Probability of Detection, POD, whistle, shout, sound-light line.

Introduction

Koopman (1946, 1980) established search theory and practice with his pioneering work during WWII. Prior to his work there was no published scientific literature on search theory. An essential part of Koopman's work was developing the concept of Effective Sweep Width (ESW)—a single numeric value of detectability for a given sensor to detect a specific search object in a unique environment. The ESW can then be used to calculate the Probability of Detection (POD), a measure of a search team's thoroughness. While determining the POD is critical to search theory it is not the ultimate goal. Instead POD is used to determine the Probability of Success (POS) in conjunction with the Probability of Area (POA). In turn POS is used to determine the Probability of Success Rate (PSR) which can be used to make decisions on the optimal allocation of resources in the field (Charnes and Cooper, 1958). For additional information on the full development of search theory and ESW see Frost (1999a, 1999b, 1999c, & 1999d).

Lateral Range

The method for estimating the ESW uses the concept of a "lateral range curve" introduced by Koopman (1946). Lateral range refers to the perpendicular distance an object is to the left or right of the searcher's track where the track passes the object. Therefore, it represents the distance from the searcher to the object at the Closest Point of Approach (CPA). A lateral range curve is a plot of the probability of detecting the object on a single pass as a function of the object's lateral range (distance) from the searcher's track. **Figure 1** shows a hypothetical relationship between POD on a single pass and an arbitrary scale of distances to the left (negative) and right (positive) of the searcher's track. Negative values are distances to the left of the searcher's track while positive values are distances to the right of the searcher's track. The shape of the lateral range curve is determined through actual field experiments. Twardy (2012) provides a recent discussion on the various shapes a lateral range may take.

Auditory search is also highly dependent on distance. However, it differs from visual search in that it is possible to know the distinct distance for each and every auditory attempt. It is also different in that each auditory signal is discrete. In fact a searcher making a continuous sound would be unable to listen to a response. It is also possible to determine if each auditory attempt of the team (whistle blast) was detected

or not detected. This unique feature allows analysis using both the CPA and to determine an alternate detection index from each discrete detection opportunity.

The lateral range method also functionally integrates all of the effects various factors have on the detection process during the experiment. Even in a fairly constant environment many factors may affect detection. Wind or rain may affect hearing at a particular point; one searcher may have better hearing than another; or the object may require several glimpses to register on the consciousness of the searcher, especially if it has a low contrast with its surroundings.
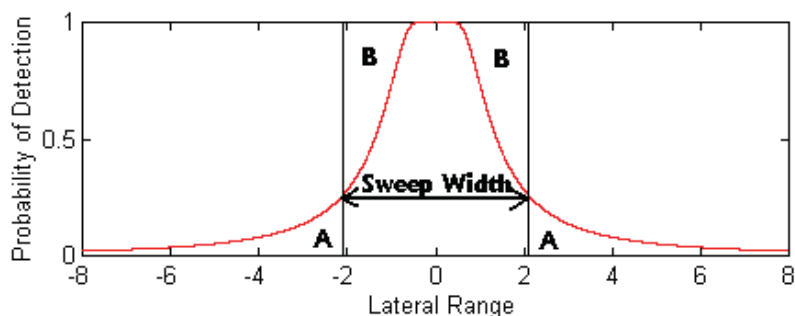
Figure 1 A Lateral Range Curve. The number of missed detections (B) inside the effective sweep width equals the detections (A) that occur outside the sweep width. This is often called the cross-over point. Figure from Frost 1999b.

Detection Index (Effective Sweep Width)

The ESW is one of the central concepts of search theory and its application to SAR. Additional information about ESW may be found in Koopman (1980), Stone (1989), and Frost (1999b).

The ESW may be thought of as the area where the number of objects *missed inside* the swath are equal to the number of objects *detected outside* the swath as shown in **Figure 1**. In more mathematical terms the ESW is also numerically equal to the area under the lateral range curve. Robe & Frost, (2002) previously showed for land search that the cross-over technique based upon finding the point where the number of cumulative detections equals the number of cumulative misses is equalvalent to calculating the area under the curve, and may in fact be superior. The technique has also been used by Koester et al (2004) and Chiacchia & Houlahan (2010) for visual search. An ESW value has not been determined for auditory search.

Probability of Detection (POD)

Successful search planning, whether in an urban, wilderness, or marine environment requires an objective standard for providing an estimate of the Probability of Detection (POD). In each of these settings the variables that describe the searcher, the search object, and the search environment will differ not only in kind but also in their influence on the estimate of the POD. What is constant, however, is that POD estimates should be based on objective measures and observations. Previous research by Koester et al (2004) found experienced searchers were unable to make accurate assessments of POD based upon subjective assessments by either the search planner or the searchers. POD depends upon coverage, which depends on three things:

- The "detection index" or ESW for the combination of search object, search environment, and sensor (e.g., auditory search from the ground) present in a given search situation,
- The amount of effort expended in searching the area, and
- The size of the area where the effort was expended.

The size of the search area requires special comment when the field technique of a sound light line is being used. The tactic places a team of searchers following a linear feature. Since each member of the team follows the same course, increasing the number of team members does not increase the total track line distance. Instead, any advantages of additional team members would be derived from factors such different abilities to hear, differences in types of whistles, differences in listening orientation, differences in attention, and other subtle factors. The size of the search area, since linear in nature, should be defined by how far off the route a POD is desired. This also simplifies the inputs and computation required to determine the POD value.

Previous Related Experiments

Koester et al (2004) reported on five visual experiments conducted in different environments for high, medium and low-visibility search object approximating prone search subjects. Chiacchia & Houlahan (2010) followed up with two additional visual experiments with similar results and using the same methodology.

No previous study used the combination of un-alerted searchers and subjects for auditory search. In addition, no previous studies have reported the POD values for clues placed directly on the track which is a common search tactic. Only two previous SAR experiments involving sound have been conducted. Martin Colwell (1992) conducted field trails to determine both visual and sound Probability of Detection (POD) in British Columbia. More specifically the experiment was conducted in a Pacific West Coast coniferous forest (Marine Temperate ecoregion division). The experimental methodology involved placing dummies in a standing position. The dummies were outfitted with inexpensive, portable, battery powered

AM radios. The radios were tuned to a local "talk" radio stations the volume adjusted to best match a person talking loudly or shouting. Manson (2009) reports that some of the researchers who had placed the subjects were also involved in the detection experiment. Colwell's results are reported as the searcher's POD based upon the spacing. While this allows creation of a lateral range curve and therefore finding the area under the curve (one method to determine an effective sweep width), this value was not calculated at the time. The actual value would be expected to be underestimated since the experiment required the searcher to also make a visual detection of the search subject in order to identify the dummies code number. Manson (2009) conducted research looking at sound in the same environment as Colwell. He looked at the relationship of loudness and range using different whistles. His experiments showed that loudness does not always directly indicate a whistles range, since pitch is also an important factor. The experiment reports an attention-getting range for each source, although this was a subjective value determined by the testers.

To date no experiment has attempted to determine the detection index or effective sweep width value for auditory search that is required to determine an objective POD. In addition, no experiment has ever been conducted to look at the use of light in getting a subject to respond. Finally, no previous experiments have looked at the real-life issue of the two-way nature (lost subject detects searcher shouts and then searchers hear subjects response) of the signal detection in the land environment.

Methodology

The methodology used was similar to visual land based experiments previously described by Koester et al (2004). That methodology was further refined and described by Koester et al (2006). An important tool used to setting up experiments is the Integrated Detection Experiment Assistant (IDEA) which is built using MS Excel. Required inputs include the projected number of search participants, the number of different types of search objects, and the Average Maximum Detection Range (AMDR). The calculator would then determine the total number of targets required, expected length of course, expected time to complete the course, and locations to place search objects (subjects). If the number of targets or course time fell outside the experimental parameters the parameter was flagged by a change in color. In addition to setting up the experiment, IDEA displays the results after inputting raw data. The experimental design calculator was a useful tool for the experiment team but is not a finished product in regards to sound-light experiments. Key differences in the experimental methodology of Koester et al (2004) and the auditory experiments are described.

Determining AMDR

During the site visit an Average Maximum Detection Range (AMDR) was obtained. The AMDR protocol was modified from the visual protocol described by Koester et al (2004) in the following ways. The AMDR was conducted by taking four measurements instead of taking sixteen measurements as specified in Koester et al (2004). The reduction was due to measuring only the extinction point (i.e., point unable to hear the whistle or shout) and reducing the number of legs from eight to four. Since the distances were large a GPS (Garmin 60CSx) was used to obtain coordinates and then measure the actual distances using Google Earth software. Since it was unknown what the difference between voice and whistle might be, both were provided. A total of three people were involved in the AMDR collection. One person stood at a fixed location. Once every two minutes a whistle was blown. Also every two minutes a shout was made. Combined, this meant either a whistle or shout would occur at the same time every minute. This allowed the "searchers" walking away from the sound source to know if the signal heard was valid. The goal is to achieve the maximum distance possible and still hear a valid signal.

Marking the track

In the sound-light experiment a two-way detection is required. The searcher must signal the subject, the subject must detect the signal and respond, and finally the searcher must detect the signal the subject sent. Therefore, it was important to control the exact location that each whistle blast occurred. This was accomplished by precisely marking the track. A one-meter measuring wheel was used to measure the course. Every 100 meters the location was marked (see **Figure two**) and the coordinate entered into a Garmin 60CSx GPS receiver. The location was indicated with an orange traffic cone marked with the appropriate distance and reflective white or red reflective tape. The cone was held in place by a fiberglass rod driven into the ground with a mallet and further enhanced with surveyor's flagging tape.

Figure 2. Cone used to mark every 100 meters along the track.

Prior to the experiment the several forms were created in order to collect data, manage experiment participants, brief participants, and ensure searcher safety.

Visual Glove experiment

The day time experiment also had clues placed on the track. The clues consisted of either high visibility clues or low-visibility clues. The high-visibility clues were white workers gloves painted with day-glo orange dazzle (paint), and the low-visibility clues were the same gloves painted gray. One low-visibility glove was left white, since it was placed on some snow. Locations for placing the gloves on the track were determined by IDEA. Searchers were informed to record any gloves they located.

Participant Recruitment

Participants were recruited mostly from Tasman Search and Rescue, the New Zealand Police, and some additional participants recruited from the Canterbury district. All searchers belonged to a search team or played an active role in search and rescue.

Basic Protocol

The sound-light experiment used search and rescue (SAR) personnel for both search subjects and searchers. The searchers used whistle blasts (day) or a combination of whistle blasts and light (night) to send a signal to the search subjects. Teams used technique taught in the SARINZ Search Methods course and corresponding student reference (Wells et al, 2012). If the search subject detected a signal (either a whistle blast or shining light) they responded by shouting "Hey, it's Bravo." Each subject was assigned a unique phonetic alphabet word to shout. The order of the words were randomized

All participants signed in on the participant sign-in sheet and were assigned to a team. Teams were staggered at a 15 minute interval. Each searcher provided basic information on the Searcher Profile form. The form is broken into three sections. Section A collects demographic information on the searcher. Section B collects physical characteristics such as hearing, vision, and height. In addition it collects information on the physical characteristics of the searcher's whistle and flashlight. Section C is filled in during debriefing and includes collected weather information, estimated PODs, and self-reporting of morale and fatigue.

The search subjects and searchers received separate briefings. The searchers were not aware of how many subjects were placed into the field. Each search team carried equipment needed to safely function in the environment (typical SAR pack) and a copy of the searcher information sheet, task assignment form, detection log, guide to determining Beaufort scale, clip board, pencil/pen plus a backup writing tool, and may have been issued a radio. The team's departure was tracked on the Team Tracking Log. Actual position reporting, once the team was dispatched was greatly facilitated by the numbered cones. Teams, instead of reporting coordinates, only need to report the closest cone number.

Upon completing the experiment (returning from the field), each team was debriefed and the detection log examined to ensure it was filled in correctly or if any questions existed. The Detection Log form has a tabular representation of the search track. A row exists for each 100 meter cone. Each detection made by the searcher is recorded on the log along with its description, time, wind condition at the time (using the Beaufort scale), and clock bearing relative to 12 o'clock being straight ahead on the track. The time was recorded for every 100 meters (cone location) where the team blew a whistle.

Current weather and changes in the weather conditions are recorded at the command post using a Kestrel 4000. The weather characteristics recorded were precipitation, cloud cover, temperature, visibility, barometric pressure, humidity, and wind speed.

Data Scoring

Data was scored in the same manner as described by Koester et al. (2004). Some differences between a visual experiment and auditory experiment are described. Subject's location were recorded by the subjects using a Garmin GPSMAP 60CSx GPS receiver and recorded on their detection logs. The GPS was setup to New Zealand Grid and the WGS84 map datum. The New Zealand Grid was used so subjects could locate themselves on the gridded map. The grid coordinate was then transformed to a decimal degree format using Franson CoordTrans version 2.3. The decimal degree subject coordinate was plotted using Google Earth. The subject's location was then compared against the previously plotted cone coordinates and the subject placement sheet which was used to place the subject's. If the location, side of the track, and distance matched it was considered a valid subject location. All subjects' had valid locations. It was also noted (using Google Earth elevation features) if the subject was uphill, downhill, or at the same level as the cone location of closest point of approach. All scoring was done by one individual to ensure consistent results. Each search object would be scored as either being detected or missed. Virtual search objects (described in Koester et al. 2004) were not placed onto the Detection Log scoring template and were all scored as misses.

Data Scoring Closest Point of Approach Method

It was possible to score the detection and non-detections using several different techniques. Detecting the search subject involved the team sending out a whistle blast at each cone and then listening for a response. A chart was prepared that showed each subjects point of closest approach or lateral range between the cone and the search subject. Each time would then be scored a "1" if the search team detected the subject's shouts and a "0" if it did not. It was possible to score the sheets rather quickly for this technique.

Data Scoring Each Cone Method

Unlike visual experiment where detections and non-detections can occur anywhere along the track (thus requiring the CPA method) sound experiments send out a discrete signal from a fixed and known location to a subject at a fixed location. Since the coordinates of each cone were recorded along with the subject's it was possible using a GIS system to measure the distance between each cone (site of the searcher's whistle blast) and the subject. The measurement ruler is precise to 0.1 meters and measurements were recorded to the closest meter (see **Figure 3**).

Figure 3 Method used to measure the distance from subject to each cone location

Each cone was then assigned to one particular subject (using midpoint between two subjects). The lateral range from that cone to the assigned subject was made. Then each team's detection or non-detection was scored for each cone. During the day experiment this results in 1327 detection opportunities versus the 115 using the CPA method. The lateral ranges were then placed into bins and the average of the distances within each bin was used to determine the lateral range for each bin.

Data entry was then made into the MS Excel based IDEA Data input Search Object 1 sheet. The clue number, lateral range (or off-track distance), and clue type were entered. Then for each searcher (using their coded searcher number) the "0" and "1" were transcribed from the scoring form into the spreadsheet.

Data Analysis

Using the information provided on the spreadsheet, another worksheet (Data Summary Object #1) automatically calculated the crossing over point of the cumulative detections and cumulative misses after the automatic sort button is clicked. The purpose of the clicking on the sort button is to sort the lateral ranges from smallest to greatest. It is then possible to calculate the detection index.

The first step in scoring was starting with the team detections. If the team heard the subject, then by default the subject had heard the team. The next phase was to determine if the subject had heard the team, even when the team did not hear the response. The trackline distance where most teams had heard the subject was recorded. Then in a separate worksheet the exact time each team reached that particular cone (trackline location) was recorded. Finally, the team's cone time was cross-referenced to the subject's detection log. If the two times matched then the subject scored a detection for that particular team. One team did not record their cone times so it was not possible to score that team.

Results

Description of Venue – Nelson Lakes St. Arnaud

Nelson Lakes National Park (established in 1956) is situated in the north of New Zealand's South Island. This park protects 102,000 hectares of the northern most Southern Alps. The park contains beech forest, craggy mountains, streams and lakes both big and small.
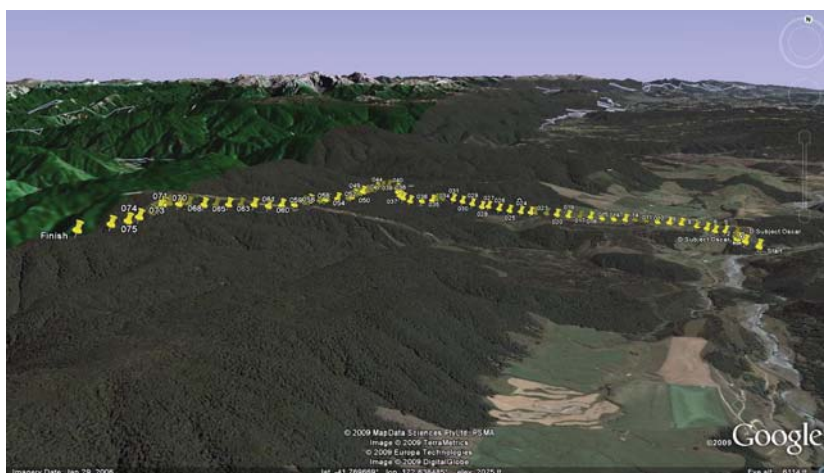
Figure 4 Google Earth view of search track with cone locations plotted

Two separate experiments were carried out at Nelson Lakes on July 18 and into the early hours of July 19, 2009. The first experiment occurred during daylight and looked at the sound line tactic and clues placed on the track. The second experiment occurred after dark. New subjects were placed in different locations. The night time experiment involved both sound and light line tactics. For each experiment the detection index can be determined by using the Closest Point of Approach (CPA) technique or from each cone's position.

Course Characteristics

Table 1 provides the general characteristics of experiment conducted at Nelson Lakes.

	Day	Night
Location	Porkia Road, Nelson Lakes	
Ecoregion	Mountainous Subtropical M230	
Season	Winter	
Length	7.5 km	
Elevation Change	467 – 983 meters	
Layout	Road	
Temperature	10-12 C	1-5 C
Wind Speed	0-10 kph	2-45 kph
Visibility	Unlimited	Unlimited – 200 meters
Cloud Cover	Partly Sunny	Clear – Foggy
Precipitation	None	Rain Moderate
Pressure	943 mb falling	943 mb
Time	11:28 – 17:57	20:36 – 01:34

Table 1 Course general characteristics

Day time Experiment – Team Detection Experiment Results

In several cases it was observed that the subject in fact detected almost all of the teams. However, almost none of the teams detected the subject. This would result in a larger detection index for the subject detecting the teams. This is in fact the actual result. The team's detection index (CPA method) was 332 meters and the subject's detection index was 401 meters.

Day time Experiment – Clue Detection

The clue detection experiment only took place during the day. The original intent was to conduct the clue detection experiment at night. Therefore, the clues were placed (using IDEA to determine the locations) the previous day. A total of 12 orange gloves were placed, 11 gray gloves, and 1 white glove (placed on snow). Out of the 15 teams that turned in a detection log only 12 completed the log in such a way it was possible to score the clues.

The last team (team 14) consisted of one of the officers who had help setup the course. He had specific knowledge about the white glove. Therefore, that particular glove from team 14 was thrown out. The range of POD% for the orange glove was 92% - 100%. The range of POD% for the low-visibility gloves was 25% - 83%. The results are summarized in table 4.

Night time Experiment – Subject Detection Light Experiment Results

In addition to the whistle blast, teams were using sound-light line tactics. Therefore, the subject also had the potential to detect the teams light. Subject's were instructed to only respond to whistle blast, but also to record when they detected light. The technique for scoring was the same method to use to determine which whistle blast matched a particular team. The detection index for subject's detecting light was 277 meters.

Predicted versus actual detections.

As part of the debriefing process, each searcher was asked to give what percentage of the potential targets did they detect? This is similar to a typical debriefing question asked on many searchers in order to obtain a "POD" value. Since the number of search objects were fixed and known, it is possible to determine how accurate the searchers were with their predicted POD versus the actual POD.

Parameter	Average Predicted	Range Predicted	Actual % Detected	Offset
Sound (Day)	29%	0-90%	33%	± 18%
Sound (Night)	38%	5-75%	59%	± 23%
Orange Glove	84%	60-100%	99%	± 21%
Gray Glove	68%	10-100%	53%	± 37%

Table 2 Searcher ability to predict Probability of Detection (POD)

Overall Summary Experiment Results

The table below provides an overall summary of both day and night experiments.

Detection Type	Method	Day Experiment ESW	Night Experiment ESW
Searchers detecting subject shouts	CPA	332 m	306 m
Searchers detecting subject shouts	Cone	276 m	262 m
Subject hearing searchers' whistle	CPA	401 m	395 m
Subject seeing searchers' light	CPA	NA	277 m
Subject detecting searchers (light or sound)	CPA	401 m	460 m

Table 3 Summary of ESW results

The Probability of Detection (POD) for a glove on the actual track during daylight.

	Number	Detection Opportunities	Average POD%	Average POD%
Orange Glove	12	144	99%	99%
Gray Glove	11	132	57%	52%
White Glove	1	11	0%	

Table 4 Summary of detection results for clue on track

Discussion

The experimental methodology was built upon the solid foundation of previous visual experiments to determine land-based detection indexes. The design and methodology of the visual experiments were in turn based upon maritime experiments conducted by the US Coast Guard Research and Development center. Key concepts such as detection opportunities, scoring each detection and non-detection, closest point of approach, looking at and for correction factors, generating lateral range curves, and using the cross-over technique to generate the actual detection index value have all been previously validated by Koester et al (2004).

The fundamental issue with sound and light detection is the two-way nature of the detection. It requires two cooperating elements that wish to find each other. The searcher desires to detect the search subject and the search subject wishes to be found. The search team sends out an initial signal (sound and/or light) and the subject must first detect the signal; recognize it for what it represents, and then respond in some fashion. Based upon conversations with SARINZ instructors it was determined the most common signal generated by search teams is a whistle blast. Then depending upon the subject type and scenario teams will sometimes augment the whistle blast by shouting the subject's name. It was then stated that approximately 90% of the time the response is a shout from the subject. Therefore, from an experimental point of view the ideal "search object" would be one that could recognize a whistle blast and then respond with a human voice. It was felt a human voice would be important since human sensory and processing systems are ideally suited to recognize a human voice across many different frequencies and hidden in background noise (Lewis et al, 2009). It was also felt the reply voice should be a short discrete signal and not a constant noise to aid in the detection of the voice. Therefore, it was decided that by using actual humans as the search subjects a detection index which actually reflects reality most closely would be obtained. More importantly, in the real world subjects don't know when they will hear a shout. The experiment methodology ensured that search subjects were un-alerted. In other words, they did not know when a team would whistle. In return, search teams were also un-alerted, since they had no idea when they would hear a reply. Future experiments should continue to use actual subjects.

While this first auditory two-way land detection experiment resulted in several key findings, the results should be viewed as preliminary and not definitive. The experiment clearly showed it was possible to obtain a detection index for sound and/or light line tactics. Furthermore, the fact that the closest point of approach method (with 115 detection opportunities) and the cone method (with 1327 detection opportunities) provided similar results indicates experiments with approximately 100 detection opportunities can be conducted. This is further bolstered by the fact that the day and night experiments resulted in a team detection index of 332 and 306 meters respectively, a difference of only 8%. The difference for the subjects hearing the whistle was only 1%.

This experiment was the first reported experiment of detection of light in a realistic search environment. Since the experiments took place in a forested area in mountainous terrain, it is expected that distances would be small. In fact, the detection index for a subject detecting the light was 277 meters. It is interesting to note that the detection index for light appeared to be independent of the detection index for sound. In some cases the subject detected the light without detecting the sound. In other cases a subject detected the sound without detecting the light. This means the overall probability of making some type of detection increases. Therefore, the detection index (ESW) for a subject detecting a team increased to 460 meters (when both sound and light were considered. It is important to realize that the detection index is not the maximum range of a possible detection but instead is either the area under the lateral range curve or the distance where the number of missed detections equals the number of detections. Depending upon conditions, it is expected that the detection index for light would be large.

While no previous studies generated a detection index for un-alerted searchers, the maximum ranges provided by other experiments do provide some insight. A previous test of several different whistle types conducted in New Zealand (B Were, personal communication, 2006) showed for the loudest whistle the maximum range was between 300 to 500 meters depending upon the conditions, compared to our results of a detection index of 400 meters for a subject detecting a whistle. After taking into account differences between alerted and un-alerted searchers, different whistle types, and the left/right nature of a detection index, the results are somewhat comparable. The first classic sound study was conducted in Canada (Coldwell, 1989). This study was conducted under more search-like conditions. The study results were reported as a lateral range curve. Using the cross-over technique found in IDEA it is possible to convert a lateral range curve into a detection index. This gives a detection index of 313 meters. The Canadian experiments were conducted in a Pacific West Coast coniferous forest. Manson (2009) also carried out a sound experiment in the Pacific West Coast coniferous forest in a recent study. This study reported both maximum and minimum attention ranges. The minimum attention getting range was a subjective measurement determined by the searcher. Depending upon the whistle type and season this ranged from 200 to 400 meters for alerted searchers. While maximum ranges do not convert to an ESW value the general range is similar.

One important finding of this paper was the observation that in many cases the subject detected the search team without the searchers detecting the subject. The experiment protocol was for a single verbal reply and for the subjects to stay in one place. In reality a missing person would most likely try to move towards the team and shout multiple times. Operationally teams would be well advised to make sure they spend sufficient time listening for a response. Those venturing into the woods are also well advised to carry a whistle and light source.

One challenge of this research was to adapt the specifics of experimental design and analysis for the specifics of sound-light line and sweep. This required direct observation of the techniques being taught and conducted by actual practitioners in the appropriate environment. This was accomplished by conducting and attending field trials, refresher courses, and field demonstrations prior to establishing the methodology. In addition, extensive conversations were conducted with knowledgeable searchers, including and going beyond the SARINZ instructor pool. This allowed for the development of the specific methodology.

The changes in methodology from previous visual methods included; marked cones every 100 meters, a modified AMDR procedure, use of trained searchers as the search subjects, use of un-alerted subjects and searchers, clear difference in signals generated by searcher and subject, creation of detection log, and measuring wind speeds at every detection opportunity. These changes were viewed as successful. In fact, this was the first auditory detection experiment where both the subjects and searchers were not alerted. As a result it was possible to document cases where the subject heard the search team, but the search team did not hear the response.

Previous visual experiments had used data collectors that were not part of the experiment staff. These "volunteer" data collectors often collected more data than needed (making scoring a little bit more difficult) but fortunately seldom left out critical information. This was the case with the sound-light experiments. All of the data collectors were searchers themselves. Almost all of the searchers successfully completed the data collection log. Only one team neglected to record the time at each cone. While the team's detections were logged, it was impossible to score the team for subject's hearing the team. This problem could easily be remedied by spot checking the logs early on in the track by a member of the experiment staff. Using searchers as data collectors was a success overall.

As a "pilot" experiment several important factors have been identified that could improve future experiments. Two key variables were not controlled. Searchers were allowed to use whatever whistle and torch (flashlight) they normally used. It was noted anecdotally that the type of whistle and torch did make a significant difference in detections. This is well worth further experimentation. Some other sources of improvement include; conducting experiments in different terrain (such as flat terrain, valley bottom,

etc.), conduct experiments in different types of vegetation or times of the year, conduct experiment to quantify potential correction factors (wind, background noise, precipitation, temperature, hearing loss, etc.), better measure participants hearing ability, record AMDR values for auditory, whistle, and torches, update IDEA, issue radios to all subjects and obtain location coordinates immediately, create a subject debriefing form, use synchronized time (available from GPS receivers), use GIS software for measurements versus Google Earth, and have staff spot check detection logs early in the experiment.

Acknowledgements

References

Charnes, A., Cooper, WW. (1958). The theory of search: optimum distribution of search effort. *Management Science*. 5:44-50

Colwell, M. (1992) Sound Sweep: A New Tool for Search Teams. V1, N2. Search and Rescue Technical Publications Series. International Search and Rescue Trade Association. Olympia, WA.

Frost, J.R. (1998c). *The theory of search: a simplified explanation.* (Rev. ed.). Fairfax, Virginia: Soza and Company, Ltd. & U.S. Coast Guard.

Frost, J.R. (1999a). Principles of search theory, part I: Detection. *Response, 17(2)*, pp. 1-7.

Frost, J.R. (1999b). Principles of search theory, part II: Effort, coverage, and POD. *Response,17(2)*, pp. 8-15.

Frost, J.R. (1999c). Principles of search theory, part III: Probability density distributions. *Response,17(3)*, pp. 1-10.

Frost, J.R. (1999d). Principles of search theory, part IV: Optimal effort allocation. *Response,17(3)*, pp. 11-23.

Koester, R., Cooper, D., Frost, J., Robe, R. (2004). Sweep Width Estimation for Ground Search and
　　　　Rescue. US. Coast Guard Operations (G-OPR. Washington, D.C.

Koester, R. (2008) Lost Person Behavior: A Search and Rescue Guide on where to Look – for Land, Air,
　　　　and Water. *dbS Productions*. Charlottesville, VA USA.

Koester, R., Guerra, N., Cooper, D., Frost, J. (2006) A Simple Guide to Conducting Ground Search and
　　　　Rescue Detection Experiments. US. Coast Guard Office of Search and Rescue (G-RPR).
　　　　Washington, D.C.

Koopman, B.O. (1946). *Search and screening* (OEG Report No. 56, The Summary Reports Group of the
　　　　Columbia University Division of War Research). Alexandria, Virginia: Center for Naval Analyses.

Koopman, B.O. (1980). *Search and screening: General principles with historical applications*. Revised.
　　　　New York, NY: Pergamon Press.

Lewis, J., Talkington, W., Walker, N., Spirou, G., Jajosky, A., Frum, C., Brefczynski-Lewis, J. (2009).
　　　　Human Cortical Organization for Processing Vocalizations Indicates Representation of Harmonic
　　　　Structure as a Signal Attribute. *The Journal of Neuroscience*. 29(7):2283-2296.

Manson, B. (2009) Using Sound in Searching for the Lost Subject: Examining Factors Affecting
　　　　Optimization. Unpublished personal communication.

Stone, L.D. (1989). *Theory of optimal search* (Second ed.). Military Applications Section, Operations
　　　　Research Society of America. Arlington, Virginia: ORSA Books.

Twardy, C. (2012, August 2) A Brief Intro to Search Theory (2 of 4) [Blog post]. Retrieved from
　　　　http://sarbayes.org on October 5, 2012.

Use of the Visual Range of Detection to Estimate Effective Sweep Width for Land Search and Rescue based on 10 Detection Experiments in North America

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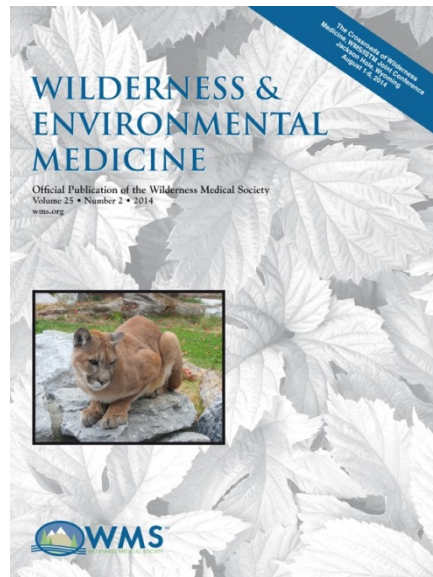
ORIGINAL RESEARCH

Use of the Visual Range of Detection to Estimate Effective Sweep Width for Land Search and Rescue Based On 10 Detection Experiments in North America

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Objective.—Standard-of-practice search management requires that the probability of detection (POD) be determined for each search resource after a task. To calculate the POD, a detection index (W) is obtained by field experiments. Because of the complexities of the land environment, search planners need a way to estimate the value of W without conducting formal experiments. We demonstrate a robust empirical correlation between detection range (Rd) and W, and argue that Rd may reliably be used as a quick field estimate for W.

Methods.—We obtained the average maximum detection range (AMDR), Rd, and W values from 10 detection experiments conducted throughout North America. We measured the correlation between Rd and W, and tested whether the apparent relationship between W and Rd was statistically significant.

Results.—On average we found $W \approx 1.645 \times Rd$ with a strong correlation ($R^2 = .827$). The high-visibility class had $W \approx 1.773 \times Rd$ (also $R^2 = .867$), the medium-visibility class had $W \approx 1.556 \times Rd$ ($R^2 = .560$), and the low-visibility had a correction factor of 1.135 ($R^2 = .319$) for Rd to W. Using analysis of variance and post hoc testing, only the high- and low-visibility classes were significantly different from each other ($P < .01$). We also found a high correlation between the AMDR and Rd ($R^2 = .9974$).

Conclusions.—Although additional experiments are required for the medium- and low-visibility search objects and in the dry-domain ecoregion, we suggest search planners use the following correction factors to convert field-measured Rd to an estimate of the effective sweep width (W): high-visibility $W = 1.8 \times Rd$; medium-visibility $W = 1.6 \times Rd$; and low-visibility $W = 1.1 \times Rd$.

Key words: search and rescue, SAR, range of detection, effective sweep width, probability of detection, search theory, missing persons

Introduction

The Introduction briefly reviews the difficulty applying formal search theory to wilderness search, and the progress since the late 1990s. The Methods section presents the experiments and statistical analyses in detail, as appropriate for an archival scientific paper. The wilderness practitioner willing to forego statistical rigor or theoretical background could begin with the Conclusions or Discussion and work backward to check details.

Search theory as a formal scientific discipline was established during the Second World War by Koopman.[1,2] A searcher must both look in the correct location and be able to detect the search object. However, the location of

the subject is unknown, and even looking in the correct location does not guarantee a detection. Search theory contends with this uncertainty by deploying available resources to achieve the maximum probability of success (POS) in the minimum time. The formula that expresses this relationship is OPOS = $\sum$ POS = $\sum$ (POD × POA).[3] That is, the overall probability of success (OPOS) is the sum over tasks of the probability of detection (POD) times the probability of area (POA). The ultimate goal of search theory is the optimal allocation of search resources. This requires determining the POD, probability of containment (POC) or POA, search area, and searcher speed. The development of search theory has been described in detail by Frost.[4–7] The POA in the land environment can be determined through the use of statistical models based on previous incidents,[8–10] models that use Monte Carlo simulation of search object movement through the environment,[11] subject matter expert input from a consensus method,[6] or by combining all of the above.[12] In the land environment another challenge is quantifying the POD.

No matter what environment, the POD depends on coverage. Coverage depends on 3 factors: the amount of effort expended in searching the area, the size of the area where the effort was expended, and the detection index or effective sweep width (ESW). A precise mathematical formula to calculate the POD from these factors is readily available.[5,13–15] Additional work describing POD can be obtained from Stone.[16] The difficulty in actually implementing the theory in the land environment has always been determining the value of the detection index or *W*. In the maritime and aeronautical search environments, *W* tables are readily available[17] thanks to extensive actual detection experiments done by the US Navy and US Coast Guard to determine key factors.[18] These tables take into consideration the 3 factors that determine *W*: the nature of the searcher (or sensor), the nature of the search object, and the environment between the 2. Actual field experiments are the only method to determine the lateral range curve, which shows the cumulative probability of a detection for all the search objects at various distances. The distance used is the closest point of approach along the track to the search object.[4] Once the lateral range curve is experimentally derived, it can be reduced to a single number (*W*) by either determining the area under the curve or using the crossover technique.[19] The crossover technique has been shown to be highly reliable and has been used to determine *W* on all 10 of the land visual experiments.[13,14,19]

Unfortunately, the land environment is far more complex and variable than the maritime environment. Bailey[20] and McNab et al[21] have identified 52 distinct ecoregions at the province level in North America and 190 sections in the contiguous United States. Mountainous regions are subject to altitudinal zonation and introduce additional complexity. Within each section can be 16 classes based on the National Land Cover Database 2006 (NLCD2006).[22] Although only 7 of the 16 classes would be expected to vary for each ecoregion section, this still leaves 1330 possibilities without considering seasonal differences. Even within each ecoregion section, the density of vegetation can change, which will affect detectability.[20] Therefore, a simple set of tables to provide *W* values in the land environment for visual search is not likely.

Because of the lag in adaptation of any new method and the lack of *W* data for local environments, most search efforts continue to use POD figures estimated by field searchers. Previous research has demonstrated that trained searchers are unable to estimate their POD values.[13,14] Early landmark experiments by Wartes in detection provided a POD value based on between-searcher spacing.[23] A decade later Perkins and Roberts developed a concept called critical separation (CS) that accounted for the search object, environment, and searcher. It also predicted POD based on between-searcher spacing.[24] However, as pointed out in a review of land search literature, these early papers did not account for search effort (formally defined as the sum of the distance traveled by each search resource within a search segment).[15] Wartes later reconsidered his position (POD based on between-searcher spacing) and recanted the POD as a function of spacing approach.[25] Importantly, the gold-standard method of calculating a retrospective POD—multiplying total track line length (effort) by local effective sweep width (*W*) values to obtain the area effectively swept, then dividing the result by the area of the searched segment to calculate coverage[5]—depends on determining *W*, currently through a time-consuming, labor-intensive setup of a local ESW experiment. In the absence of a previous *W* experiment, this effort is simply not possible when a lost-person incident has begun. The land search-and-rescue (SAR) community, therefore, could benefit greatly from a simple, objective procedure that obtains *W* values without conducting full-blown detection experiments.

Methods

DEFINITIONS

Area Effectively Swept (Z/AES)—Previously defined as the product of the total track length (TTL) of all searcher paths in the area searched and the sweep width (*W*): AES = TTL × *W*.[14]

Average Maximum Detection Range (AMDR)—An experimental process that involves obtaining both the average range of detection (*Rd*) and the average range of extinction (*Re*) from 8 legs (angles).[14]

Coverage (C)—Previously defined as the ratio of the area effectively swept (AES) to the area searched (A): $C = AES/A$.[14]

Effective Sweep Width (ESW)—Previously defined as either the area under the lateral range curve or the distance in which the number of detections equals the number of missed detections. In this paper ESW denotes the experimental process for measuring, and *W* denotes the value measured (see *W*).[14]

Probability of Area/Containment (POA/POC)—Previously defined with both terms being identical. The terms refer to the probability of the search object being in a given defined geographic space. The term POA is typically used by the wilderness community and the term POC is used by the aeronautical and maritime community.[26]

Range of Detection (Rd)—The average of linear distances at which a search object is first detected when moving toward it from multiple angles.

Range of Extinction (Re)—The average of linear distances at which a search object is no longer seen after it has been detected while moving away from it from multiple angles.

Search Visibility Class—A broad description of the amount of contrast between the search object and the environment. Search objects were placed into 1 of 3 classes; high visibility, medium visibility, or low visibility.

Sweep Width (W)—The numerical value in units of linear distance that represents a given object's detectability with a given sensor operating in a given set of environmental conditions; determined from an ESW experiment (see ESW). Also called effective sweep width.[14] The word *sweep* in this context is not to be confused with its common use in expressions like sweep [search] an area, perform *n* sweeps of an area, sweep searching (as a tactic), and so on.

ESW EXPERIMENTS

A total of 10 ESW experiments have been conducted by 3 separate research teams. Each experiment is shown in Table 1. The data derived for this paper's analysis come from these experiments conducted around North America. The methodology for the first 5 experiments is described by Koester et al.[14] In all of these experiments the AMDR distance was determined by collecting 16 measurements (Figure 1). The measurements consisted of an *Rd*, when the search object was first

Table 1. Location and characteristics of effective sweep width experiments

| Source	Location	State	EcoRegion	Province	Terrain	Season
Koester et al.[14]	Shenandoah National Park	VA	M221	Central Appalachian Broadleaf Forest	Mountainous	Winter
Koester et al.	Gifford National Forest	WA	M242	Cascade Mixed Forest	Flat	Summer
Koester et al.	Lansdowne	VA	231	Southeastern Mixed Forest	Flat	Summer
Koester et al.	Lincoln National Forest	NM	M311	Great Plains Steppe and Shrub	Mountainous	Spring
Koester et al.	Mt. Diablo State Park	CA	M261	California Coastal Chaparral Forest and Shrub	Mountainous	Summer
Chiacchia et al. (in preparation)	Manheim	PA	M221	Central Appalachian Broadleaf Forest	Mountainous	Spring
Chiacchia and Houlahan[13]	State Game Land 203	PA	220	Eastern Broadleaf Forest (continental)	Hills	Winter
Twardy[27]	Mt. Greylock	MA	M210	Adirondack-New England Mixed Forest	Mountainous	Summer
Chiacchia and Houlahan	State Game Land 203	PA	220	Eastern Broadleaf Forest (continental)	Hills	Summer
Chiacchia et al. (in preparation)	State Game Land 203	PA	220	Eastern Broadleaf Forest (continental)	Hills	Summer
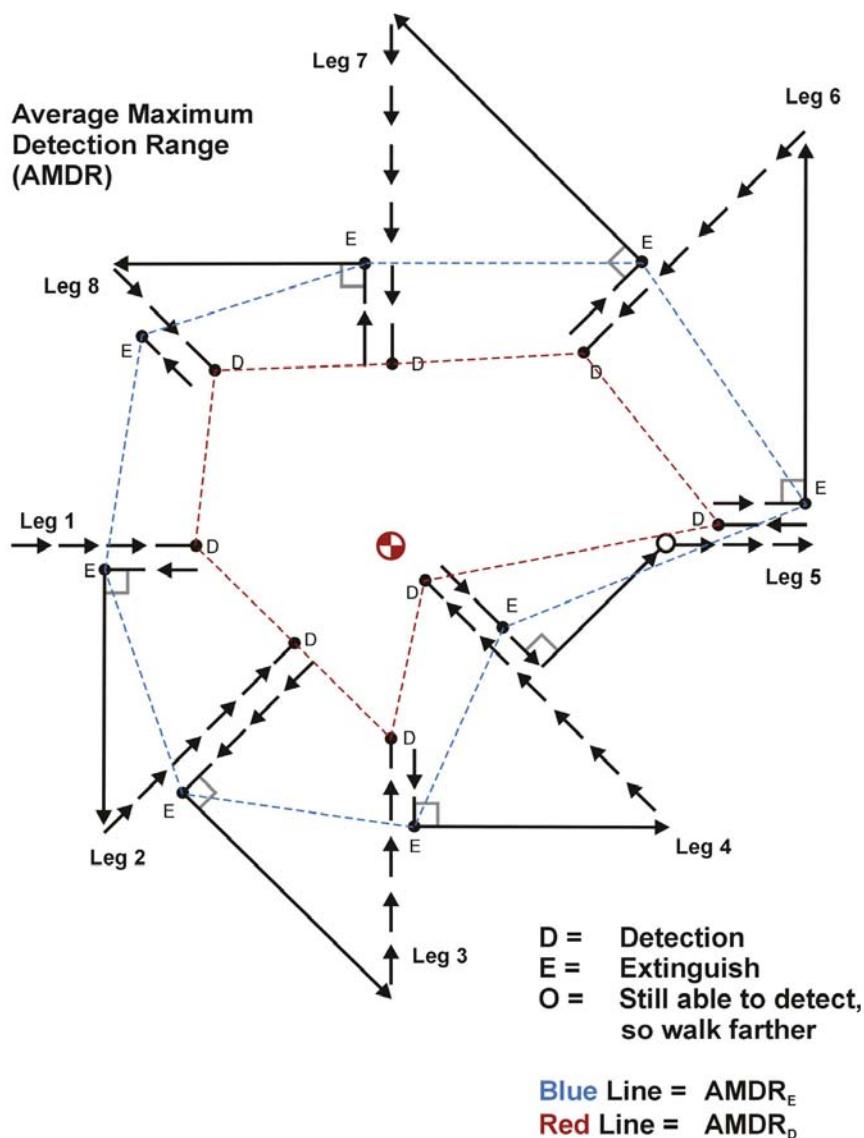
Figure 1. Procedure to determine average maximum detection range (AMDR).

detected, and the *Re*, when the object once located could no longer be detected. The AMDR value is not the maximum distance at which the search object can be detected from any angle but instead an average of both *Re* and *Rd*. The *Rd* value will almost always be less than the AMDR value except in the rare case when *Rd* equals *Re* from every angle. AMDR measurements used either a tape measure or an electronic rangefinder with precision ± 0.5 m (different models of the Nikon rangefinder were used). All AMDR distance measurements were taken on the experimental courses by the research team. The AMDR distance measurement was always taken before the experiment, which ranged from a week to a day before the experiment, and was entered into the Integrated Detection Experiment Assistant (IDEA) worksheet.[28]

The worksheet then automatically generated a randomized plan for the ESW course. Search objects were high-visibility manikins (stuffed white coveralls with orange safety vests), medium-visibility manikins (stuffed dark blue coveralls), or low-visibility manikins (stuffed olive drab coveralls). In addition, gloves were used for clue-sized objects. Gloves were either high-visibility (Day-Glo orange or royal blue) or low-visibility (dark brown or painted olive). Searchers then walked the track, made detections, and a data collector recorded all detections. All 10 experiments were conducted in the daytime. After the experiment, detections and misses were entered into the IDEA worksheet, and the software provided the *W* value using the crossover technique.[14,19]

The first 5 experiments were conducted by Koester et al[14] and documented in a US Coast Guard report. Subsequent ESW experiments used a refined version of IDEA, and made small changes as required by local conditions.[28] Experiment 6 was held at Manheim, Pennsylvania. Half of the experimental team from Koester et al[14] observed and provided assistance to the new team led by Chiacchia et al. (manuscript in preparation). The seventh experiment was conducted at Mt Greylock in the Berkshire Mountains of Massachusetts.[27] The course was set up by Twardy and Frost (a member of the experimental team from Koester et al). They deviated from the method in the following ways: they had only 3 targets, the high-visibility adult manikin, assorted white shoes for high-visibility clues, and assorted brown or black shoes for low-visibility clues.

The remaining 3 experiments were all conducted in the northern part of State Game Lands 203 in Marshall Township, Pennsylvania, led by Chiacchia. The results of 3 of those experiments were reported by Chiacchia and Houlahan[13] along with the slight modification they made to the methodology. The changes to the methodology included one versus two AMDR process estimate, use of manufacturer-dyed brown, royal blue, and orange gloves versus spray-painting white gloves, slight modification of lateral range for search object location, and modification of some of the forms. (Chiacchia's 2010 course was calibrated using figures from the 2008 experiment, but used manufacturer-dyed gloves of much different hue. Therefore, on August 24, 2011, Chiacchia and Houlahan obtained AMDR and *Rd* distances for the objects used in the 2010 experiment. We use these data to ensure an apples-to-apples comparison.)

STATISTICAL ANALYSIS

To conduct the analysis for this paper, the raw data and results from IDEA were obtained from each of the 10 experiments. Before analysis, each search object was classified as either high visibility, medium visibility, or low visibility by visual contrast. The high-visibility class included orange gloves, white shoes, and white or orange adult-size manikins, and high-contrast royal blue gloves used in 1 experiment. The AMDR value and *W* value were recorded from IDEA. All results were entered into a Microsoft Excel spreadsheet. (Note that the *W* values reported in the current study from Chiacchia and Houlahan are those obtained by pooling data from all their searchers, and so differ slightly from *W* values reported in that study, which were median or mean values of *W* calculated for individual searchers.[13])

We performed statistical analysis 1) to find the 95% CIs for our parameters, and 2) to determine whether relationships were statistically significant. We performed our tests using GraphPad Prism version 5.04 for Windows (GraphPad Software, San Diego, CA, www.graphpad.com). All tests were 2-tailed. Trends were subjected to a least-squares analysis using a linear function with the *y*-intercept constrained to 0. To compare the slope parameters so derived, the values, standard errors, and degrees of freedom from these analyses were in turn used to perform either analysis of variance (ANOVA— when more than 2 values were being compared) or a parametric *t* test (when 2 values were compared). Note that to perform this calculation, we added 1 to each degree of freedom value to regenerate the correct n.[29] For the ANOVA results, individual differences were subjected to a Tukey's multiple comparison test, with the minimum significance level set to $P \leq .05$ (note, however, that the software identifies higher levels of significance as well). All graphs show uncertainties as standard deviations.

This particular study was conducted using preexisting data taken from IDEA software generated during previous detection experiments. None of the data uniquely identified any individual that participated in the experiments. Instead, the *W* values are composite values obtained by aggregating all individual results. The AMDR values and hence *Rd* values were obtained by members of the research team, all of whom are also members of SAR teams and well-versed in the risks of the outdoors.

Results

OVERALL DATA FROM ALL EXPERIMENTS

A total of 27 search objects were used in all 10 experiments. High-visibility search objects (both adult- and clue-sized) were used 13 times, medium-visibility objects were used 5 times, and low-visibility objects were used 9 times. The AMDR, *Rd*, and *W* were determined for all search objects.

AMDR VERSUS *Rd*

Rd is much easier (Figure 2) to measure than AMDR, and there is clearly a tight relationship between them. (AMDR measured both *Rd* and *Re* at 8 points around the compass. Formally, AMDR also requires using either a laser rangefinder or tape measure to enhance repeatability. However, field measures of *Rd* could use pace counting to further speed measurement, because an *Rd* value always involves moving toward the search object.) Therefore, we decided to determine whether *Rd* is an acceptable stand-in for AMDR. Figure 3 shows the correlation between AMDR and *Rd* from the 27 values.
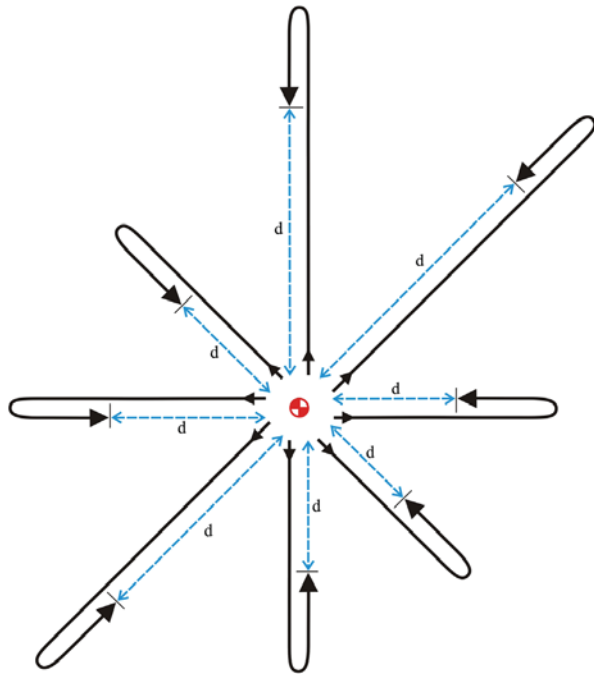
**Figure 2.** Procedure to determine range of detection (*Rd*).

The slope is 0.9687 and R^2 is .9974. SAR field resources would be well served by only collecting measurements for the *Rd* value.

Rd VERSUS *W* FOR ALL SEARCH OBJECTS

For the 27 search objects, a positive correlation was found between the *Rd* and the *W* values. The slope of the best-fit straight line with a *y*-intercept of 0 is 1.645 with a 95% CI of 1.475 to 1.816. The R^2 value is .8268. This suggests that if *Rd* is known, then a relationship exists that can be used to estimate the *W* value.
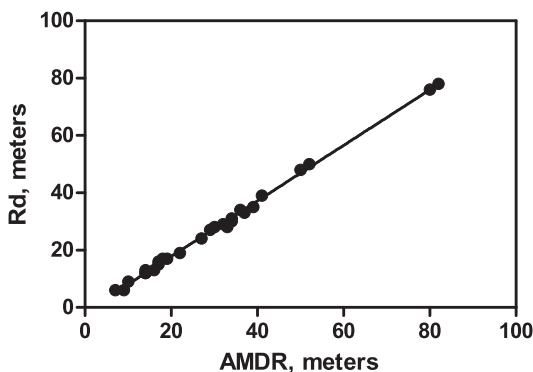
Figure 3. Relationship between range of detection (Rd) and average maximum detection range (AMDR).
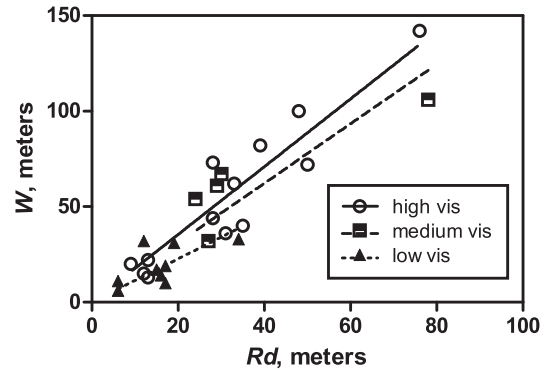
Figure 4. Relationships between effective sweep width (*W*) and range of detection (*Rd*) for 3 classes of visibility.

Rd VERSUS *W* BY SEARCH VISIBILITY CLASS

It might be expected that more accurate *Rd*-to-*W* multipliers may be derived if each search visibility class (high-, medium-, and low-visibility) is examined individually. Indeed, in earlier experiments, placing low-visibility clues according to high-visibility AMDR values caused the vast majority of gloves not to be detected.[13] Figure 4 shows the relationship between *Rd* and *W* for the 3 search object classes fit to individual curves. The 3 separate trend lines are all produced with a best-fit straight line with a *y*-intercept of 0. Table 2 summarizes the results. The high-visibility class indeed shows a better fit (higher R^2 value) than the pooled estimate. However, the other visibility classes are more scattered, possibly because there were fewer medium- and low-visibility search objects. An ANOVA was conducted to test the slopes of each fit: the *P*-value for the ANOVA is .0073 (3 groups, $F = 6.081$, $R^2 = .3363$), strong evidence that at least some slopes are different. A pairwise Tukey post hoc test confirms the slopes for the high- and low-visibility objects differed at the $P < .01$ level. The slope for the medium-visibility objects did not differ significantly from the other slopes.

Discussion

The results of this paper provide a practical and scientific technique to estimate *W* for visual search in the land environment where no ESW experiment has yet been done. The positive correlation between *Rd* and *W* ($R^2 = .83$) will allow for a meaningful estimate of *W* in the field. This estimate could, when appropriate, be determined by search teams before performing their assigned tasks. Alternatively, the *W* estimation (*Rd* procedure) could be a task in itself, performed early in the search to acquire *W* values to be used in assessing later teams' efforts. In either case, the searchers can use the simpler *Rd* as an excellent stand-in for the more cumbersome

Table 2. Comparison of range of detection versus effective sweep width among the 3 visibility classes and all data combined

Variable	Combined	High visibility	Medium visibility	Low visibility
n	27	13	5	9
Slope	1.645	1.773	1.556	1.135
95% CI	1.475–1.816	1.545–2.002	1.037–2.076	0.7634–1.507
R^2	.827	.867	.560	.319

AMDR. (The extremely high correlation between Rd and AMDR [$R^2 = .997$] is not particularly surprising because the Rd value was already half of the measurements that comprise the AMDR process, and the Re was usually within a few meters of the Rd. In only 22% of the cases was the AMDR greater than Rd by more than 4 m. The slope of the best-fit straight line was 0.97, meaning for field purposes Rd = AMDR.)

RECOMMENDED CORRECTION FACTOR(S) FOR FIELD USE

We found a correction factor of 1.645 from Rd to W to be a good overall estimate ($R^2 = .83$). In other words, if an Rd of 10 m was measured, then the estimated W would be 16.45 m. The actual value, although previously unpredicted, is not completely unexpected. The Rd value is a 1-sided value from 1 direction. In reality, a searcher will look both left and right. If measured Rd is close to the true maximum detection range, then the theoretical maximum for a correction factor for Rd is 2, but otherwise, Rd and W have no specific theoretical correlation.[19] Therefore, it does make sense that we found correction factors of less than 2. Recall that the AMDR procedure uses or creates an alerted searcher, whereas the ESW experiments use unalerted searchers. While conducting AMDR measurements, the researchers never missed the search object. During the actual ESW experiments, searchers missed search objects even with lateral ranges of 0 (walking on or over a search object without detection). In fact, early research into visual detection and visibility identified factors that are related to an alerted searcher versus an unalerted searcher. These factors include improved vigilance, general knowledge of location, and knowledge of size and general time of when a detection should take place.[30] More recently, research on the effects of being cued (alerted) on vigilance tasks similar to visual searching have been reported.[31] It can also be hypothesized that the unalerted searcher correction factor varies with contrast or visibility. For this reason we examined the correction factor for high-, medium-, and low-visibility search objects separately.

For the 3 different visibility classes, we found different correction factors for Rd-to-W. The correction factors for high visibility (1.773), medium visibility (1.556), and low visibility (1.135) show an appropriate relationship. It would be expected that the unalerted searcher "penalty" would be the least for a high-visibility search object and its W value would approach the theoretical limit of twice the Rd value. The low-visibility search objects would require more-focused searching and without being primed would be more difficult to detect. This is an important point regarding the psychology of visual search: the smaller multipliers for the lower-visibility color objects are not simply because of the difficulty of seeing them against the background environment. That is already accounted for in the lower Rd values for these objects. Rather, the smaller multipliers stem from the fact that these objects are less likely to be noticed by an unalerted searcher, quite apart from their lower visibility.

Although the correlation between Rd and W was relatively strong for the high-visibility class ($R^2 = .87$), it was less so for the medium-visibility ($R^2 = .56$) and low-visibility ($R^2 = .32$) classes. There are a number of possible reasons, chiefly sample size and intrinsic variability. Although the high-visibility value was based on a count of 13, the medium-visibility (n = 5) and low-visibility (n = 9) values derived from smaller samples. Additional experiments could help improve the R^2 values. The medium-visibility (dark blue) search objects presented more variability. In some environments and under some light conditions they were more visible, while under other conditions they could be difficult to visualize.

Only the difference between the high- and low-visibility correction factor (slope) was statistically significant. This might have been caused by the limited number of experiments involving medium-visibility search objects. If this is in fact the case, then the best solution is to conduct additional experiments with medium-visibility search objects.

Although our results have shown fairly robust evidence of a difference in correction factor between high- and low-visibility objects, it should be noted that the standard deviations of these measurements are still fairly

large compared with the measurements—ranging from about 25% to nearly 50%. Therefore, at this time these figures should not be used with more than 2 significant digits.

Although the overall correction factor, 1.6, could possibly be used, our data indicate that it probably supplies an overly optimistic POD for low-visibility objects, and therefore may not be the best choice. Preferably, operational correction factors for high- and low-visibility objects should be 1.8 and 1.1, respectively. Our data do not currently indicate a significant difference between the medium-visibility and other objects; with caution, the measured value of 1.6 (which, interestingly, is the same as the overall value) may be used. However, a more conservative approach would be to use the low-visibility value of 1.1 for medium-visibility objects.

OPERATIONAL SIGNIFICANCE OF THE 95% CONFIDENCE INTERVAL

In this section we show that under plausible search assignments, the uncertainty in our estimates corresponds to about an 8% difference in estimated POD. This is a substantial improvement on the 60% uncertainty in subjective estimates. Recall that ultimately W has no purpose other than to calculate a POD. (W is not to be confused with tactical spacing between searchers. In general it has no relationship to spacing. There are special cases in which a relationship may be found, subject to certain assumptions and constraints.) Therefore, we calculate the variation in POD between the lower and upper W estimates, using plausible operational assumptions.

Assume for the sake of comparison that the size of the search area is 1 km^2 and a team of 9 searches the area completely and expends sufficient effort to obtain a total trackline length (TTL) of 45,000 m (5 passes × 1,000 m × 9 searchers). With an Rd value of 20 m, the estimated $W = 20$ m × 1.645 = 32.9 m; using the exponential detection function, the POD value obtained will be 77%.

If we replace the correction factor of 1.645 with the lower bound value of 1.475 (estimated $W = 20$ m × 1.475 = 29.5 m), the calculated POD value becomes 73%. If the upper bound of 1.816 is used (estimated $W = 20$ m × 1.816 = 36.3 m), then the calculated POD value becomes 80%. Therefore, for a typical SAR scenario, the difference in POD between using the bottom (73%) and the top (80%) of the 95% range for the slope of the regression is less than 10%. This small difference would not likely be operationally significant in a higher coverage scenario. If we reduce coverage to 3 passes, the difference is still only 8% (lower bound 54%, upper bound 62%). The impact would be greater at even

smaller coverage, but smaller coverage often means searchers are no longer in sight of each other, and this tactic is often avoided for safety reasons.

AMDR, *Rd*, AND *Re*

It is important to recall that the AMDR (and hence Rd and Re) measurements were taken by researchers separate from the actual ESW experiments, and that the researchers knew beforehand where the search objects being assessed were located. By comparison with the ESW experiment itself, in which object locations were randomized and the searchers did not know where to look, the researcher was always alerted (cued) to the relative position, shape, and color of the search object. In addition, during the 8 legs of the AMDR process, the researchers would notice and learn local landmarks that would assist in detecting the object. Therefore, it is not surprising that even for the low-visibility search objects only small differences existed between Rd and Re.

For searchers in the field who wish to estimate W, the Rd value will be sufficient. Because searchers would continue to walk toward the search object after making the detection, they can use their pace count (already part of field training) to determine the distance.[32]

The AMDR procedure is, however, more exacting, and may still be appropriate for calibrating ESW experiments. However, we have seen that it has the same correlation with W as does Rd, so would be unjustified in field operations.

We recommend searchers adopt an 8-point field estimate of detectability (Rd procedure as shown in Figure 2), and use that to estimate W and then estimate POD as described in this paper, to wit, as a function of coverage. This is far more objective and defensible than having search teams subjectively estimate POD directly by introspection.

GENERAL DISCUSSION

In this paper, we suggest a relationship exists between Rd and W. We have described the strength of the relationship as a correlation. However, this is merely an empirical correlation—we do not yet know the theoretical relationship, and a linear model may be incorrect. Nevertheless, the robustness of the empirical relationship and the far simpler method of measuring Rd suggest an important operational role for using Rd to estimate W.

An AMDR or Rd measurement only considers environmental factors for the relatively small area it encompasses, whereas an ESW experiment integrates the entire track. Nevertheless, the data suggest it is still possible to estimate the much more inclusive W value from the

relatively small area used during the AMDR or *Rd* process. During actual search incidents, a search team may encounter highly variable terrain within its assigned search area. It is suggested in these circumstances that teams conduct *Rd* measurements as needed to reflect the conditions encountered.

LIMITATIONS AND FURTHER WORK

Although the 10 experiments were conducted in 6 different ecoregion provinces and in flat, hilly, and mountainous terrain, all but 1 of the experiments were conducted in the humid temperate domain. Therefore, the correction factor may have a potential bias.

The results describe empirical field results. It provides no explanation for what is causing the results. It can be hypothesized that differences may be related to an alerted and unalerted searcher or differences in searching technique. Searchers approach the search object straight-on while conducting an AMDR or *Rd* procedure. On actual searches and during the ESW experiments, most of the detections occurred while looking to the side (2–4 o'clock and 8–10 o'clock).

W is a complex product of the nature of the search object (size and contrast), the searcher (visual searching and cogitation), and the environment in between the 2. Maritime *W* tables allow the user to look up *W* based on the type and size of search object (person in the water, life raft, etc.), search platform (helicopter, aircraft, ship, platform altitude, etc.), and environment (visibility, wind, seas). For the land search, it is hypothesized (but incompletely tested) that the critical factors might be type of search object (size and visibility), search sensor (ground searcher, dog team, mounted team, etc.), and the environment. The land environment is far more complex and variable than the maritime environment; however, critical factors may be the density of vertical obstructions, the height of ground cover, and the density of ground obstructions such as logs and rocks. Future work along these lines strictly tied to ESW experiments would be difficult and time-intensive. However, if an *Rd* measurement can be used as a proxy for *W*, it might be possible to conduct the types of experiments on land that can lead to the development of tables like the maritime *W* tables. In addition, as we have noted, *Rd* measurements can be used to provide a quick estimate for environments for which *W* values are not yet available. In the future this will allow for experiments to look at factors (via remote sensing) that may prospectively predict putative *W* values before resources are placed into the field. A prospective *W* allows for planners to use search per unit of time.[7]

RECOMMENDATIONS FOR SEARCHERS

It is suggested that searchers and search planners can start using the correction factors at this time. While in terrain representative of their assigned search area, the team should place an object representative of the objective of the search effort. In most cases this will be something human-sized displaying the same visibility class the subject is believed to be wearing. The *Rd* measurement should be conducted (as shown in Figure 2) taking the mean of the 8 different legs. Searchers may pace the distance from where they make the detection to the actual test object (which might be another team member). If searchers encounter significantly different terrain within their assigned area, they can repeat the procedure.

Neither the *Rd* value nor the *W* value has any particular tactical significance. Instead it is used for calculating the POD. In fact, unless searchers extend their visual searching beyond *W*, they will almost certainly achieve a smaller *W*. In addition, if searchers need to spend additional effort to investigate areas of interest or see around obstructions, this extra effort will be captured by the total trackline length and increase the POD value accordingly. Search teams only need to report the *Rd* distance, the number of searchers, and a trackline distance (obtained by a GPS receiver odometer or estimated from time searching and team velocity). Search management can then estimate the POD using formal search theory as shown in Table 3.

Conclusions

This paper shows it is possible to derive a correction factor that allows one to estimate *W* from 8 field measurements of the *Rd*. This correction factor is based on 10 experiments conducted across North America in different types of terrain with 3 different research teams using the same methodology. Determining the *Rd* with a 4-person search team would take about 5 minutes. Determining *W* through an experiment requires typically over 200 hours and considerable planning. The latter expense in time and personnel has proved the greatest hurdle to the meaningful use of ESW on actual incidents. Although additional work remains, especially in the dryer ecoregions, it is suggested that search planners can start using the correction factor of 1.8 for high-visibility, 1.6 for medium-visibility, and 1.1 for low-visibility search objects at this time.

Acknowledgments

Table 3. Measurements and calculations required to determine the probability of detection

Letter	Term	Units	How obtained/derived
Rd	Range of detection	Length	Obtained in field
W	Sweep width	Length	$W = Rd \times Cf$ (correction factor)
			$Cf = 1.1$ low-visibility class
			$Cf = 1.6$ medium-visibility class
			$Cf = 1.8$ high-visibility class
TL	Track line	Length	$TL =$ time searching $\times$ velocity
			or
			Measured by GPS/GNSS odometer
TTL	Total track line	Length	$TTL = TL \times n$ (number of searchers on team)
Z	Area effectively swept	Area	$Z = TTL \times W$
A	Area	Area	Measured from map or from GIS
C	Coverage	No unit	$C = Z/A$
POD	Probability of detection	Percentage	$POD = 1 - e^{-C}$

References

1. Koopman BO. *Search and Screening*. OEG Report No 56. Alexandria, VA: Center for Naval Analyses; 1946. Available at: http://www.cna.org/sites/default/files/research/1100005600.pdf. Accessed November 5, 2013.
2. Koopman BO. *Search and Screening: General Principles With Historical Applications*. Rev. ed. New York, NY: Pergamon Press; 1980.
3. Charnes A, Cooper WW. The theory of search: optimum distribution of search effort. *Manage Sci*. 1958;5:44–50.
4. Frost JR. Principles of search theory, part I: detection. *Response*. 1999;17:1–7.
5. Frost JR. Principles of search theory, part II: effort, coverage, and POD. *Response*. 1999;17:8–15.
6. Frost JR. Principles of search theory, part III: probability density distributions. *Response*. 1999;17:1–10.
7. Frost JR. Principles of search theory, part IV: optimal effort allocation. *Response*. 1999;17:11–23.

8. Syrotuck WG. *Analysis of Lost Person Behavior*. Mechanicsburg, PA: Barkleigh Productions; 1975.

9. Koester RJ, Stooksbury DE. Behavioral profile of possible Alzheimer's disease patients in Virginia search and rescue incidents. *Wilderness Environ Med*. 1995;6:34–43.

10. Koester RJ. *Lost Person Behavior: A Search and Rescue Guide on Where to Look—for Land, Air, and Water*. Charlottesville, VA: dbS Productions; 2008.

11. Lin L, Goodrich MA. A Bayesian approach to modeling lost person behaviors based on terrain features in wilderness search and rescue. *Comput Math Organ Theory*. 2010;16:300–323.

12. Twardy CR, Jones N, Goodrich M, et al. MapScore: a portal for scoring probability maps. Paper presented at: Military Operations Research Society Symposium, June 2012; Colorado Springs, CO.

13. Chiacchia KB, Houlahan HE. Effectors of visual search efficacy on the Allegheny Plateau. *Wilderness Environ Med*. 2010;21:188–201.

14. Koester RJ, Cooper DC, Frost JR, Robe RQ. *Sweep Width Estimation for Ground Search and Rescue*. Washington, DC: US Dept of Homeland Security, US Coast Guard Operations (G-OPR); 2004.

15. Cooper DC, Frost JR, Robe RQ. *Compatibility of Land SAR Procedures With Search Theory*. Washington, DC: US Coast Guard Operations (G-OPR); 2003.

16. Stone LD. *Theory of Optimal Search*. 2nd ed. Catonsville, MD: INFORMS; 2004.

17. International Maritime Organization and International Civil Aviation Organization (IMO/ICAO). *International Aeronautical and Maritime Search and Rescue Manual*. Vol II. Mission Co-ordination. London/Montreal: International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO); 2010.

18. Edwards NC Jr, Mazour TJ, Hover GL, Osmer SR. *Factors Affecting Coast Guard SAR Unit Visual Detection Performance*. Washington DC: US Coast Guard, Office of Research and Development; 1981.

19. Robe RQ, Frost JR. *A Method for Determining Effective Sweep Widths for Land Searches: Procedures for Conducting Detection Experiments*. Alexandria, VA: Potomac Management Group; 2002.

20. Bailey RG. *Description of the Ecoregions of the United States. 2nd ed revised and expanded, Misc Publ No 1391*. Washington DC: US Dept of Agriculture, Forest Service; 1995.

21. McNab WH, Cleland DT, Freeouf JA, Keys JE Jr, Nowacki GJ, Carpenter CA. *Description of "Ecological Subregions: Sections of the Conterminous United States."* Washington, DC: US Dept of Agriculture, Forest Service; 2005.

22. Fry J, Xian G, Jin S, et al. Completion of the 2006 National Land Cover Database for the Conterminous United States. *Photogrammetric Eng Remote Sensing*. 2011;77:858–864.

23. Wartes J. *An Experimental Analysis of Grid Sweep Searching*. Sunnyvale, CA: Western Region Explorer Search and Rescue (ESAR); 1974.

24. Perkins D. Critical Separation: Its Role in Search Management in Theory and Practice. In: LaValla PH, ed. *Probability of Detection (POD) Research and Other Concepts for Search Management*. Olympia, WA: Emergency Response Institute; 1989.

25. Wartes J. Letter to the Editor. *Response*. April/May 2005:25.

26. Cooper DC, Frost JR. *Selected Inland Search Definitions*. Olympia WA: DC Cooper; 2000.

27. Twardy CR. Berkshires 2006 Sweep Width Experiment. SARBayes. 2013. Available at: http://sarbayes.org/search-theory/berkshires-2006-sweep-width/. Accessed December 4, 2013.

28. Koester RJ, Guerra N, Frost JR, Cooper DC. *A Simple Guide to Conducting Ground Search and Rescue Detection Experiments*. Washington DC: US Dept of Homeland Security, US Coast Guard Office of Search and Rescue (G-RPR); 2006.

29. GraphPad Software. How does Prism compare the slopes of linear regression lines? If there are three or more lines, how can I account for multiple comparisons? GraphPad Website. Available at: http://www.graphpad.com/support/faqid/248. Accessed August 6, 2012.

30. Duntley SQ, Gordon JI, Taylor JH, et al. Visibility. *Appl Opt*. 1964;3:549–598.

31. Gunn DV, Warm JS, Nelson WTBRS, Schumsky DA, Corcoran KJ. Target acquisition with UAVs; vigilance displays and advanced cuing interfaces. *Hum Factors*. 2005;47:488–497.

32. National Association for Search and Rescue, Cooper DC, ed. *Fundamentals of Search and Rescue*. Sudbury, MA: Jones and Bartlett Publishers; 2005.

Section 3: Search Optimization

Final Report SBIR Phase I: Lost Person Locator for First Responders

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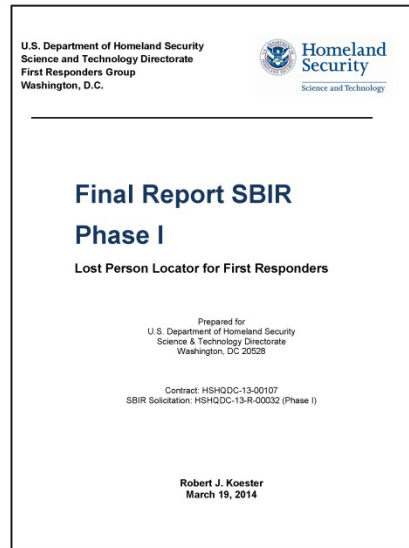
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Lost Person Locator for First Responders

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Final Report SBIR Phase II: Search and Rescue Initial Response Tools

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