National Search and Rescue Literature Review:

Annotated Bibliography – Report 1

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DRDC CORA CR 2013-014
February 2013

Defence R&D Canada
Centre for Operational Research and Analysis

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Contractor's Document Number: 5298-002 Version 04
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Defence R&D Canada – CORA

Contract Report
DRDC CORA CR 2013-014
February 2013

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NATIONAL SEARCH AND RESCUE LITERATURE REVIEW: ANNOTATED BIBLIOGRAPHY – REPORT 1

FOR

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Ottawa, Ontario

17 April 2012

Document No. 5298-002 Version 04

APPROVAL SHEET

Document No. 5298-002 Version 04

Document Name: National Search and Rescue Literature Search Annotated Bibliography

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17-04-2012

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17-04-2012

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17-04-2012

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REVISION HISTORY

Revision	Reason for Change	Origin Date
Version 01	Initial document issued	23 January 2012
Version 02	Incorporated revisions proposed by Client	07 February 2012
Version 03	Addition of Task 2 Part 2 in report	27 March 2012
Version 04	Final document	17 April 2012
Version 05	Revisions by scientific authority	29 November 2012

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ABSTRACT

This document is a deliverable associated with the project entitled “National Search and Rescue Literature Review”. The purpose of this project was to conduct a literature review and develop an annotated bibliography of existing analytical techniques, models and methods that have been applied to the delivery of search and rescue. This report was completed by CAE Professional Services (Canada) Inc. (CAE PS) under Task #132 for contract #W7714-083663/001/SV to Defence Research & Development Canada (DRDC) Centre for Operational Research and Analysis (CORA).

This document contains an annotated bibliography and review of Canadian and foreign search and rescue studies related to resource allocation/basing models, response posture, strategic policy, tactics and procedures and search techniques associated with aeronautical, maritime and humanitarian search and rescue. The first objective of the current work was to conduct a literature search and create an annotated bibliography outlining the papers resulting from the search. The second objective was to summarize two papers chosen by the Technical Authority. The two papers chosen were from the resource allocation/basing models category. The papers summarized were:

Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology. European Journal of Operational Research, 196, 1086 à 1096 et Azofra., M., Pereze-Labajos, C. A., Blanco, B., & Achutegui, J. J. (2007). Optimum placement of sea rescue resources. Safety Science, 45, 941 à 951.

RÉSUMÉ

Ce document est issu du projet d'analyse de documents sur les opérations nationales de recherche et de sauvetage. Ce projet visait à faire une analyse documentaire et à constituer une bibliographie annotée des techniques, des modèles et des méthodes d'analyse en vigueur qui ont déjà été appliqués à la prestation des services de recherche et de sauvetage. Ce rapport a été produit par CAE Professional Services (Canada) Inc. (CAE PS) dans le cadre de la tâche no 132 pour le contrat no 7714-083663/001/SV confié au Centre d'analyse et de recherche opérationnelle (CARO) de Recherche et développement pour la défense Canada (RDDC).

Ce document contient une bibliographie annotée et une analyse des études canadiennes et étrangères sur les services de recherche et de sauvetage sous l'angle des modèles d'allocation et de mise en place des ressources, de la posture de réponse, de la politique stratégique, des tactiques et des procédures et des techniques de recherche associés aux opérations de recherche et de sauvetage aéronautiques, maritimes et humanitaires. Le premier objectif des travaux actuels était d'effectuer une analyse documentaire et de créer une bibliographie annotée énumérant les documents mis au jour par cette recherche. Le second objectif était de résumer deux articles choisis par l'autorité technique. Les deux articles choisis traitent des modèles d'allocation et de mise en place. Les documents résumés sont :

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EXECUTIVE SUMMARY

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The authors of the U. S. Coast Guard Air Station Location with Respect to Distress Calls paper developed a methodology to analyze if the current and future locations of bases are adequately located to ensure the shortest response times. The U. S. Coast Guard did this in response to acknowledgement that this issue, based on where distress calls originate, has not been fully investigated. The resulting model is a spatial statistics model that also provides a simulation and optimization methodology that allows for determining the best location for search and rescue bases based on call locations that vary over time.

The authors of the second paper, Optimum Placement of Sea Rescue Resources, proposed two models that would be used to determine the best location for search and rescue resources such as ships and aircraft. The two models were the individual and zonal distribution models. Both models consider a variety of complex variables that contribute to accidents at sea and take into account that accidents occur in a sometimes hostile and constantly changing environment. Finally, both models use historical accident data to help determine resource allocation. The factors that are included in both distribution models are characteristics of the accident, types of accidents and their severity, distribution of resources, placement of resources assigning indicators of suitability to locations and cost-effectiveness.

SOMMAIRE

Ce document est issu du projet d'analyse de documents sur les opérations nationales de recherche et de sauvetage. Ce projet visait à faire une analyse documentaire et à constituer une bibliographie annotée des techniques, des modèles et des méthodes d'analyse en vigueur qui ont déjà été appliqués à la prestation des services de recherche et de sauvetage. Ce rapport a été produit par CAE Professional Services (Canada) Inc. (CAE PS) dans le cadre de la tâche no 132 pour le contrat no 7714-083663/001/SV confié au Centre d'analyse et de recherche opérationnelle (CARO) de Recherche et développement pour la défense Canada (RDDC).

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Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology. European Journal of Operational Research, 196, 1086 à 1096 et Azofra., M., Pereze-Labajos, C. A., Blanco, B., & Achutegui, J. J. (2007). Optimum placement of sea rescue resources. Safety Science, 45, 941 à 951.

Les auteurs de l'article « U. S. Coast Guard Air Station Location with Respect to Distress Calls » ont créé une méthodologie pour déterminer si les emplacements actuels et futurs des bases sont bien choisis pour assurer les délais d'intervention les plus courts. La garde côtière américaine a fait cette analyse après avoir constaté que cette question, compte tenu de l'origine des appels de détresse, n'avait pas été étudiée en profondeur. Le modèle qui en est issu est un modèle de statistiques spatiales qui offre aussi une méthode de simulation et d'optimisation permettant de déterminer l'emplacement idéal des bases pour les opérations de recherche et de sauvetage, selon l'origine des appels, qui varie au fil du temps.

Les auteurs du deuxième article, « Optimum Placement of Sea Rescue Resources » proposent deux modèles pour déterminer le meilleur emplacement des ressources de recherche et de sauvetage, comme les navires et les aéronefs. Les deux modèles sont les modèles de configuration individuelle et zonale. Les deux tiennent compte d'un éventail de variables complexes qui contribuent aux accidents en mer et du fait que les accidents surviennent parfois dans un environnement inhospitalier et en constant changement. Enfin, les deux modèles ont été élaborés à partir de données sur des

accidents passés afin de faciliter l'allocation des ressources. Les facteurs intégrés aux deux modèles sont représentatifs, qu'il s'agisse des accidents, des types d'accidents et de leur gravité, de la répartition des ressources, de l'affectation des ressources, et ils indiquent ce qui convient selon les emplacements ainsi que le rapport coût-efficacité.

1 INTRODUCTION

This document is a deliverable associated with the project entitled “National Search and Rescue Literature Review”. The purpose of this project was to conduct a literature review and develop an annotated bibliography of existing analytical techniques, models and methods that have been applied to the delivery of search and rescue. This report was completed by CAE Professional Services (Canada) Inc. (CAE PS) under Task #132 for contract #W7714-083663/001/SV to Defence Research & Development Canada (DRDC) Centre for Operational Research and Analysis (CORA).

1.1 Background

The DRDC CORA SAR System Performance Analysis Toolset (SPAT) Applied Research Project(ARP) requested a literature search and review of analytical techniques, methods and models that have been developed to analyse the delivery of search and rescue. The literature review incorporated both Canadian and foreign studies related to the following areas: resource allocation/basing models, response posture and timeline studies, strategic policy, tactics and procedures and search techniques. The primary focus of the survey was aeronautical SAR, but maritime and humanitarian SAR categories were also considered.

1.2 Objective

There were two objectives of this report. The first was to conduct a literature search and develop an annotated bibliography of existing analytical techniques, methods and models that have been developed and used to examine the delivery of search and rescue. The second was to summarize two papers chosen by the Technical Authority.

1.3 This Document

This document is the deliverable required for Task 2 of this project. This document is structured according to the following:

- Section 1 – Introduction: Identifies the project background and objectives;
- Section 2 – Method: Identifies the method used to conduct the literature search;
- Section 3 – Annotated Bibliography: Provides the annotated bibliography of the papers found during the literature search. In most instances, the bibliographic reference and abstract are presented for each paper without bias or opinion; and
- Section 4 – Summary review of two resource allocation/basing model papers.

2 METHOD

The literature search was conducted using the following online archives and databases:

- Google Scholar;
- Google Book;
- Defense Technical Information Center (DTIC); and
- United States Coast Guard website.

Google Scholar produced the most exhaustive list of papers. The papers identified during the literature search consist of internal technical reports, contractual reports, academic dissertations and peer-reviewed journal articles. Additionally, sources used in the papers chosen for the annotated bibliography were reviewed to see if any of those papers were pertinent for this report. All papers are open source documents.

The following keywords and keyword combinations were used in this literature search:

- Resource Allocation/Basing Models
  - Search and rescue;
  - Search and rescue and resource allocation;
  - Search and rescue and staffing bases;
  - Search and rescue and basing models;
  - Basing models;
  - Resource allocation;
  - Resource allocation models;
  - Aeronautical search and rescue and resource allocation;
  - Aeronautical search and rescue and basing models;
  - Maritime search and rescue and resource allocation; and
  - Maritime search and rescue and basing models.
- Search Techniques
  - Search and rescue;

- Search and rescue search techniques;
- Search and rescue UAVs;
- Aeronautical search techniques;
- Aeronautical search and rescue techniques;
- Maritime search techniques;
- Maritime search techniques; and
- Search and rescue search techniques models.

- Response Posture and Timeline Studies
  - Search and rescue;
  - Search and rescue and response studies;
  - Search and rescue and timeline studies;
  - Aeronautical search and rescue and timeline studies;
  - Aeronautical search and rescue and response times;
  - Aeronautical search and rescue and response posture;
  - Maritime search and rescue timeline studies;
  - Maritime search and rescue response times; and
  - Maritime search and rescue and response posture.
- Strategic Policy
  - Search and rescue and strategic policy;
  - Aeronautical search and rescue and strategic policy; and
  - Maritime search and rescue and strategic policy.
- Tactics and Procedures
  - Search and rescue;
  - Search and rescue tactics;

- Search and rescue procedures;
- Aeronautical search and rescue tactics;
- Aeronautical search and rescue procedures;
- Maritime search and rescue tactics; and
- Maritime search and rescue procedures.

3 ANNOTATED BIBLIOGRAPHY

This section presents the results of the literature search according to the following categories: resource application/basing models, search techniques, response posture and timeline studies, strategic policy and tactics and procedures. Although some papers were applicable to multiple categories, each paper is recorded in a single category where it was deemed most applicable.

The authors take no credit for the material summarized for each paper listed in this section. The information is either a direct extraction taken from the abstract of each subject paper or an abbreviated summary of the introduction/objective of the paper. There is no original material introduced or opinion offered regarding the quality or relevancy of each paper.

3.1 Resource Allocation/Basing Models

Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology. *European Journal of Operational Research, 196,* 1086-1096. doi:10.1016/j.ejor.2008.04.010

We study the problem of suitably locating U.S. Coast Guard air stations to respond to emergency distress calls. Our goal is to identify robust locations in the presence of uncertainty in distress call locations. Our analysis differs from the literature primarily in the way we model this uncertainty. In our optimization and simulation based methodology, we develop a statistical model and demonstrate our procedure using a real data set of distress calls. In addition to guiding strategic decisions of placement of various stations, our methodology is also able to provide guidance on how the resources should be allocated across stations.

Armstrong, R. D., & Cook, W. D. (1979). Goal programming models for assigning search and rescue aircraft to bases. *Journal Operational Research Society, 30(6),* 555-561.

This paper develops several variations of a goal programming model for optimally allocating a fleet of search and rescue aircraft to a fixed set of available and potentially available bases. In addition, the model determines the number of aircraft of each type from each base (at which that type has been stationed) to assign to the various search locations. The criterion for optimality is to maximize the probability of locating each distress in a specified time. These models are then modified to include fleet planning issues. Solution procedures relating to the models are discussed.

Azofra, M., Perez-Labajos, C. A., Blanco, B., Achutegui, J. J. (2007). Optimum placement of sea rescue resources. *Safety Science, 45,* 941-951.

In countries with autonomous regional governments, the positioning of the national sea rescue resources is often a permanent source of friction between the national and regional authorities. This friction usually resurges after any heavily publicised accident. However, the process of planning sea rescue resources and their distribution in the various locations should be carried out according to scientific criteria. The aim of the present work is to build a tool which allows sea rescue resources to be assigned objectively. To this end, we formalise a general methodology based on gravitational models which allows us to define individual and zonal distribution models. Also, a practical application of the zonal model is performed, assigning 'sea rescue boats' to a segment of the coast where there are three ports.

Colina-Azofra, M., & Rodriguez-Achutegui, J. J. (2004). Assignation of resources for sea rescue: An application to the Basque Country. *Journal of Maritime Research, 1(2),* 45-63.

The problem of the location of sea rescue resources generates certain controversies which are generally revived after accidents which have had a great social impact. The aim of the present paper is to formulate a methodology based on gravity models allowing sea rescue resources to be assigned. To this end, a study has been made of the problems of accident assessment, of ports and airports and their relation with the above and of zonification. Finally, an empirical application of this methodology to the Basque Country has been made.

Cottam, H., & Shadbolt, N. (1998). Knowledge acquisition for search and rescue planning. *International Journal of Human-Computer Studies, 48,* 449-473.

There is an increasing adoption of knowledge-level modelling within expert system development. However, it has had less impact in the generic areas of planning, scheduling and resource allocation. In this paper, we outline the development of a knowledge-level modelling approach within the domain of planning for search and rescue (SAR). Existing problem solving models for planning are almost exclusively derived from an analysis of the functional architectures of classic AI planners such as TWEAK and NONLIN. We argue that this makes their suitability for directly assisting knowledge acquisition questionable. Our approach makes a clear distinction between domain-derived knowledge-level models and those derived from computational architectures. We describe how the combination of these two types of models can achieve clear benefits within the course of KBS development. The paper includes extensive descriptions of the SAR domain, which illustrate the practical knowledge engineering problems that our approach attempts to address.

Cottam, H, Shadbolt, N., Kingston, J., Beck H., Tate, A. (1995). *Research and Development in Expert Systems XII,* 309-325.

The increased use of intelligent decision support systems has created a demand for efficient acquisition, implementation and maintenance of the knowledge required by

such systems. The field of knowledge level modelling has developed as a means to this end. This has led to the construction of methodologies for KBS development that facilitate a generic approach to knowledge acquisition. Such generic approaches have achieved great success when applied to various domains, yet have thus far largely neglected the generic areas of planning, scheduling and resource allocation. In this paper we outline the development of such a generic approach within the domain of planning for Search and Rescue. Our generic approach makes a distinction between domain derived knowledge level models and those derived from systems. We describe how the combination of these two types of model can achieve definite benefits within the course of KBS development.

Findler, N. V., & Sengupta, U. K. (1994). Multi-agent collaboration in time-constrained domains. *Artificial Intelligence in Engineering, 9(1),* 39-52.

Timeliness is usually an indispensable attribute of planning and problem solving for resource allocation in command, control and communication systems. The success of such a system is judged on its ability to respond to scheduled and unscheduled tasks within a permissible time period. The response is based on a plan that covers the following activities: resource allocation, plan execution and monitoring and dynamic plan mending, if necessary. Decision making for resource selection can become very time consuming when there are many resources and the number of constraints is large. In a changing environment of multiple agents, restrictive organizational structures and strict communication protocols may cause intolerable further delays. Traditional approaches to planning in deterministic environments require a predictable amount of time to produce and execute plans. However, given more time, such systems usually cannot improve on the plans. In this paper we describe a multi-agent resource scheduler which uses a prioritized rule base to model decision making under the constraints of time. We also discuss *dynamic scoping* as a negotiation technique for inter-agent cooperation and *constrained lattice-like* communications as an optimized message routing strategy. Finally, we present some empirical results from a sequence of experiments.

Ghami, A. (2010). *Modeling and analysis of Canadian Forces RSOM hubs for northern operations.* Paper presented at the Summer Simulation Multiconference, Ottawa, Ontario, Canada.

This paper presents an analysis of a Reception, Staging and Onward Movement (RSOM) hub concept to support Canadian Forces (CF) Northern operations. RSOM hubs are permanent or temporary staging bases for cross-loading between strategic and tactical lift during military deployment and sustainment operations. Performance measures were developed to assess the effectiveness and the responsiveness of different hub options. An optimization model was also developed to determine the optimal number and locations of hubs. Deployment scenarios to different Northern locations were simulated and assessed. Sensitivity analysis was conducted to examine the impact of different operational parameters on hub performance. The study indicated that the RSOM hub concept would offer potential cost avoidance and response time

reduction on deployment lift for Northern operations and could be a potential strategy for improvement of the CF domestic support capability.

Guitouni, A., Jabeur, K., Allouche, M., When, H., & Happe, J. Application of search theory for large volume surveillance planning, *11th International Conference Information Fusion,* June 30-July 3, 2008, 8 pages.

DRDC Valcartier has initiated, through a PRECARN partnership project, the development of an advanced simulation test bed called CanCoastWatch. The main focus of this test bed is to study net-enabled concepts such as distributed information fusion algorithms and architectures, dynamic resources and networks configuration management, and self-synchronising units and agents. The test bed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms. In this paper, we present the integration of a planning tool based on search theory concept: SARPlan. In particular, we discuss the original idea of combining fusion results to build a containment probability distribution according to the search theory approach. This paper presents the results and discusses future development.

Park, S. (2007). *A multi-objective decision-making model for resource allocation in humanitarian relief.* (Unpublished master's thesis). Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio.

This thesis addresses the critical resource allocation in the initial days of a disaster relief operation. One of the most important and essential components of relief operations is the allocation of scarce resources to accomplish the relief efforts. Every operation for disaster relief needs various critical resources including (but not limited to) personnel, equipment, supplies, or simply finances. Several research efforts for disaster relief have suggested methods to allocate scarce resources across a variety of competing objectives and programs in a disaster relief operation. Many of those efforts focused on optimizing a mathematical programming model subject to budget constraints. However, capturing the values of the decision-maker(s) in such a model is relatively unexplored. The lack of clear organizational values contributes to the inconsistency in practice and hinders effective resource allocation across the disaster relief system. The purpose of this study is to develop a multi-objective decision-making (MODM) model to incorporate the decision-maker(s) value trade-offs in the disaster relief resources allocation problem. The notional model is based on a hurricane and flood scenario, and the decision window for the resource allocation is the critical first 72 hours after the initial damage assessment has been made. The value focused thinking (VFT) process is used to capture the value trade-offs, and the resulting value hierarchy is optimized via a mathematical programming model to solve the multi-objective resource allocation problem.

3.2 Search Techniques

Abi-Zeid, I., & Frost, J. R. (2004). SARPlan: A decision support system for Canadian Search and Rescue Operations. *European Journal of Operational Research, 162,* 630-653. doi:10.1016/j.ejor.2003.10.029

We present SARPlan, a geographic decision support system designed to assist the Canadian Forces in the optimal planning of search missions for missing aircraft. Its primary purpose is to ensure that the available search resources are deployed in a way that will maximize the missions' probability of success. The optimization modules are based on search theory, on gradient search methods and on constraint satisfaction programming. We include results that demonstrate that SARPlan improves the performance when compared to the current manual method. This improvement translates to an increase in the chances of finding lost aircraft and survivors, resulting in more saved lives. Another benefit of using SARPlan is a potential decrease in the operations costs. In 2001, SARPlan was the winner of three prestigious excellence awards in the information technology domain.

Abi-Zeid, I., Nilo, O., & Lamontagne, L. (2011). A constraint optimization approach for the allocation of multiple search units in search and rescue operations. *INFOR, 49(1),* 15-30.

Search and Rescue (SAR) comprises the search for and provision of aid to persons who are, or who are feared to be, in distress or in imminent danger of loss of life. Time is a crucial factor for survivors who must be found quickly and search planning may get complex in the case of a large search area and multiple search resources. The problem we address in this paper is that of defining and assigning multiple non-overlapping rectangular sub-areas to search units (search aircraft) such that the search plan is operationally feasible and the total probability of success is maximized. We present algorithms we developed for the search resources allocation problem for aeronautical SAR incidents when multiple indivisible searchers are present. These algorithms are based on classical search theory and on constraint programming. We assume that the search effort is continuous and measured by track length, that the search object is stationary and that search is conducted in discrete space. We present experimental results for a realistic SAR case overland.

Ablavasky, V., & Snorrason, M. (2000, August). Optimal search for a moving target: A geometric approach*. Paper presented at the meeting of AIAA Guidance, Navigation, and Control Conference & Exhibit, Denver, Colorado.*

The problem of optimal (or near-optimal) exhaustive search for a moving target is of importance in many civilian and military applications. Search and rescue in open sea or in sparsely-populated areas and search mission for previously-spotted enemy targets are just a few examples. Yet, few known algorithms exist for solving this problem and none of them combine the optimal allocation of search effort with the actual computation

of trajectories that a searcher must (and physically can) follow. We propose a divide-and-conquer geometric approach for constructing optimal search paths for arbitrarily-shaped regions of interest. The technique is both generalizable to multiple search agents and extensible in that additional real-life search requirements (maneuverability constraints, additional information about the sensor, etc.) can be incorporated into the existing framework. Another novelty of our approach is the ability to optimally deal with a search platform which, due to design constraints, can only perform detection while moving along straight-line sweeps.

Breivik, O., & Allen, A. (2008). An operational and rescue model for the Norwegian Sea and the North Sea. *Journal of Marine Systems, 69(1-2),* 99-113. doi 10.1016/j.jmarsys.2007.02.010

A new operational, ensemble-based search and rescue model for the Norwegian Sea and the North Sea is presented. The stochastic trajectory model computes the net motion of a range of search and rescue objects. A new, robust formulation for the relation between the wind and the motion of the drifting object (termed the leeway of the object) is employed. Empirically derived coefficients for 63 categories of search objects compiled by the US Coast Guard are ingested to estimate the leeway of the drifting objects. A Monte Carlo technique is employed to generate an ensemble that accounts for the uncertainties in forcing fields (wind and current), leeway drift properties, and the initial position of the search object. The ensemble yields an estimate of the time-evolving probability density function of the location of the search object, and its envelope defines the search area. Forcing fields from the operational oceanic and atmospheric forecast system of The Norwegian Meteorological Institute are used as input to the trajectory model. This allows for the first time high-resolution wind and current fields to be used to forecast search areas up to 60 hours into the future. A limited set of field exercises show good agreement between model trajectories, search areas, and observed trajectories for life rafts and other search objects. Comparison with older methods shows that search areas expand much more slowly using the new ensemble method with high resolution forcing fields and the new leeway formulation. It is found that going to higher-order stochastic trajectory models will not significantly improve the forecast skill and the rate of expansion of search areas.

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

Background: Although lost-person search managers try to direct search efforts quantitatively, it has historically been difficult to quantify the efficacy of search efforts accurately. The effective-sweepwidth (ESW) methodology represents an avenue for accomplishing this goal but has not yet been widely disseminated among practitioners. **Methods:** We obtained ESW values in the summer and winter in a typical disturbed-forest environment in southwest Pennsylvania. We used nonparametric statistics to compare individual ESW values for two types of search objects detected by 18 summer and 20 winter searchers, cumulating the *P* values for similar comparisons and

correcting for false discovery via a stepped method. **Results:** We detected robust differences (all at *P* <.001) associated with search object color, season, and vegetation thickness. In contrast with earlier studies, we found a significant correlation between individual searchers' ESWs for different search objects and different types of vegetation (*P* <.001). We also found that adolescent searchers had significantly lower ESW values than adults (*P* <.002). Apparently significant positive correlations between time spent on the course or field search experience and ESW disappeared when teens were excluded from the comparisons. **Conclusions:** These results (the first comparison of seasonal ESW effects in identical terrain) represent the first statistical demonstration that the ESW methodology provides more than enough resolution to answer fundamental questions about the efficacy of visual search for lost persons by human searchers. They also add support to the imperative of operationally disseminating these methods among search-and-rescue practitioners, and offer some initial operational lessons for search managers.

Choisnard, J., Power, D., Davidson, F., Stone, B., Howell, C., & Randell, C. (2007). Comparison of C-band SAR algorithms to derive surface wind vectors and initial findings in their use in marine search and rescue. *Canadian Journal of Remote Sensing, 33(1),* 1-11.

This paper presents a comparison of existing algorithms to derive surface winds from synthetic aperture radar (SAR) satellites and investigates their use in drift forecasting for search and rescue purposes. Specifically, SAR-derived winds from RADARSAT-1 and ENVISAT advanced synthetic aperture radar (ASAR) data at 1.5 km resolution are compared with scatterometer-derived winds. Three approaches were used to retrieve the wind vector from the SAR data, including an optimal inversion method combining SAR data and background numerical weather prediction, the geophysical model function CMOD-IFR2 with an a priori wind direction, and a technique that uses the backscatter values corresponding to two neighboring subimages with slightly different incidence angles. Our comparisons of SAR wind mapping with scatterometer winds from QuikSCAT and ERS-2 produced a root mean square error (RMSE) of 1.5 m/s. The optimal inversion method seems very promising and appears to be the best choice for assimilation of SAR-derived winds into operational wind products with respect to the datasets presented here. Additionally, the suitability of SAR imagery for search and rescue operations is reviewed. It is recommended that a method should be explored to automatically assimilate such data into operational search and rescue tools. Use of SAR winds in a search and rescue drift model is shown herein to produce improved drift trajectories on a number of search and rescue targets (e.g., life boat, sail boat, person in water).

Croft, J. L., Pittman, D. J., & Scialfa, C. T. (2007). Gaze behavior of spotters during an air-to-ground search. *Human Factors, 49(4),* 671-678.

Objective: This study was designed to develop methods for evaluating the gaze behaviors of spotters during air-to-ground search and to compare field-derived

measures with previous lab results. Secondary aims were to assess adherence to a prescribed scan path, evaluate search effectiveness, and determine the predictors of task success. **Background:** Crashed aircraft must be located quickly to minimize loss of life, often requiring visual search from the air. **Method:** Eye movements were measured in 10 volunteer spotters while they searched from the air for ground targets. Visual acuity, contrast levels, and performance on a lab-based search task were also measured. **Results:** Results were similar to those of previous lab-based studies of air-to-ground search. Task success could be predicted best from a combination of gaze and laboratory variables, and as in previous research, experience was not one of them. **Conclusions:** In both lab and field research, performance is poor. Improvements in air search and rescue success will depend upon improvements in training, the refinement of scan tactics, changes to the task methods or environment, or modifications to parameters of the search exercise. **Application:** Spotters were unable to reliably search their assigned area, which has implications for the current search training program and in-the-air protocol.

Ferguson, D. (2008, February). *GIS for wilderness search and rescue.* Paper presented at the ESRI Federal User Conference, Washington, DC.

The objective of any search and rescue mission is to locate the missing subject and return them to a stable and safe environment. To do this, search managers must employ tactics that are efficient and do not pose unnecessary risk to rescue personnel. Modern search strategies involve the use of behavioral profiling, probability theory, terrain interpretation and resource management. Geographic information systems provide a platform to integrate these various elements into an effective tool for managing search operations. This paper discusses the application of GIS to manage the search for a missing autistic youth in the Dolly Sods Wilderness area of West Virginia. Through this example, details are provided for segmenting the designated search area into probability regions based on statistical analysis and a behavioral profile of the missing subject. An operational base map was developed by integrating digital raster graphics, elevation datasets, and aerial imagery with various shape files in order to further segment the probability regions into searchable areas. Attribute tables provided a database to track resources, clue logs and area coverage as well as performing basic probability estimates. Recommendations for the use of GIS during search operations focus on improving search efficiency and effectiveness, as well as reducing operational costs and response times with the goal of finding the missing subject as quickly as possible.

Furukawa, T., Bourgault, F., Lavis, B., & Durrant-White, H. F. (2006). Recursive Bayesian search-and-tracking using coordinated UAVs for lost targets. *Proceedings of the IEEE International Conference on Robotics and Automation, Orlando, FL,* 2521-2526.

This paper presents a coordinated control technique that allows heterogeneous vehicles to autonomously search for and track multiple targets using recursive Bayesian

filtering. A unified sensor model and a unified objective function are proposed to enable search-and-tracking (SAT) within the recursive Bayesian filter framework. The strength of the proposed technique is that a vehicle can switch its task mode between search and tracking while maintaining and using information collected during the operation. Numerical results first show the effectiveness of the proposed technique when a found target becomes lost and must be searched for again. The proposed technique was then applied to a practical marine search-and rescue (SAR) scenario where heterogeneous vehicles coordinated to search for and track multiple targets. The result demonstrates the applicability of the technique to real search world scenarios.

Furukawa, T., Durrant-White, H. F., &Lavis, B. (2007). The element-based method – theory and its application to Bayesian search and tracking. *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, San Diego, CA,* 2807-2812.

This paper presents the element-based method, which can be used for recursive Bayesian estimation (RBE) in robotic operations such as search and tracking involving moving targets. The use of shape functions to define a set of irregularly shaped elements allows the target PDF to be continuously, and thus accurately, represented over the target space. A comparison with the grid-based method first shows that the element-based method requires less than 10% of the number of nodes to achieve the same accuracy. The application of the element-based method to marine search-and-rescue (SAR) scenarios then demonstrates its ability for effective SAR whilst maintaining collected information.

Goodrich, M. A., Morse, B. S., Engh, C., Cooper, J. L. & Adams, J. A. (2009). Towards using UAVs in wilderness search and rescue: Lessons from field trials. *Interaction Studies, 10(3),* 455-481.

Wilderness Search and Rescue (WiSAR) is the process of finding and assisting persons who are lost in remote wilderness areas. Because such areas are often rugged or relatively inaccessible, searching for missing persons can take huge amounts of time and resources. Camera-equipped mini-Unmanned Aerial Vehicles (UAVs) have the potential for speeding up the search process by enabling searchers to view aerial video of an area of interest while closely coordinating with nearby ground searchers. In this paper, we report on lessons learned by trying to use UAVs to support WiSAR. Our research methodology has relied heavily on field trials involving searches conducted under the direction of practicing search and rescue personnel but using simulated missing persons. Lessons from these field trials include the immediate importance of seeing things well in the video, the field need for defining and supporting various roles in the search team, role-specific needs like supporting systematic search by providing a visualization tool to represent the quality of the search, and the on-going need to better support interactions between ground and video searchers. Surprisingly to us, sophisticated autonomous search patterns were less critical than we anticipated, though advances in video enhancement and visualizing search progress, as well as ongoing

work to model the likely location of a missing person, open up the possibility of closing the loop between UAV path-planning, search quality, and the likely location of a moving missing person.

Goodrich, M. A., Morse, B. S., Gerhardt, D., Cooper, J. L., Quigley, M., Adams, J. A., & Humphrey, C. (2007). Supporting wilderness search and rescue using a camera-equipped mini UAV. *Journal of Field Robotics, 25(1-2),* 89-110. doi 10.1002/rob.20226

Wilderness Search and Rescue WiSAR entails searching over large regions in often rugged remote areas. Because of the large regions and potentially limited mobility of ground searchers, WiSAR is an ideal application for using small human-packable unmanned aerial vehicles UAVs to provide aerial imagery of the search region. This paper presents a brief analysis of the WiSAR problem with emphasis on practical aspects of visual-based aerial search. As part of this analysis, we present and analyze a generalized contour search algorithm, and relate this search to existing coverage searches. Extending beyond laboratory analysis, lessons from field trials with search and rescue personnel indicated the immediate need to improve two aspects of UAV-enabled search: How video information is presented to searchers and how UAV technology is integrated into existing WiSAR teams. In response to the first need, three computer vision algorithms for improving video display presentation are compared; results indicate that constructing temporally localized image mosaics is more useful than stabilizing video imagery. In response to the second need, a goal-directed task analysis of the WiSAR domain was conducted and combined with field observations to identify operational paradigms and field tactics for coordinating the UAV operator, the payload operator, the mission manager, and ground searchers.

Jacobson, S. H., McLay, L. A., Hall, S. N., Henderson, D., & Vaughan, D. E. (2006). Optimal search strategies using simultaneous generalized hill climbing algorithms. *Mathematical and Computer Modelling, 43,* 1061-1073.

Optimal search strategies for conducting reconnaissance, surveillance or search and rescue operations with limited assets are of significant interest to military decision makers. Multiple search platforms with varying capabilities can be deployed individually or simultaneously for these operations (e.g., helicopters, fixed wing or satellite). Due to the timeliness required in these operations, efficient use of available search platforms is critical to the success of such missions. Designing optimal search strategies over multiple search platforms can be modeled and solved as a multiple traveling salesman problem (MTSP). This paper demonstrates how simultaneous generalized hill climbing algorithms (SGHC) can be used to determine optimal search strategies over multiple search platforms for the MTSP. Computational results with SGHC algorithms applied to the MTSP are reported. These results demonstrate that when limited computing budgets are available, optimal/near-optimal search strategies over multiple search platforms can be obtained more efficiently using SGHC algorithms compared to other

generalized hill climbing algorithms. Applications and extensions of this research to other military applications are also discussed.

Jusoff, K. (2008). Search and rescue (SAR) operations for the missing Bell 206 Long Ranger helicopter in Sarawak, Malaysia using near real-time airborne hyperspectral imaging system. *Disaster Prevention and Management 17(1),* 94-103.

Purpose: The aim of this paper is to present the latest advances in real-time airborne hyperspectral sensing applications in identifying and mapping the likely spots to be zeroed in for the SAR operations. Design/methodology/approach: A Sabah Air GAF Nomad N22B low altitude fixed wing aircraft equipped with an AISA airborne hyperspectral imaging system flew over the steep gradient carved by very narrow valleys, ridges, precipitous escarpments and ravines, extensively covered by thick virgin forest of the highlands. The study was carried out by an AISA sensor, which is a complete system that consists of a compact hyperspectral sensor head, miniature GPS/INS sensor for precise positioning, data acquisition unit and Caligeo post-processing software. Findings: These UPM-APSB's AISA flights demonstrated that quality real-time hyperspectral images could be pre-processed on-board the aircraft and become accessible to the SAR committee members for quick ground SAR within two hours after the flight. The combined geospatial information technologies were a major breakthrough in the Malaysian SAR real-time imaging technique. Originality/value: It is expected that future precise locations of the suspected targets can be transmitted via very high frequency radio communications and become accessible to the SAR ground members such as the commandos VAT 69. Real-time airborne hyperspectral imaging will benefit strategic SAR and help reduce the loss of lives in future helicopter crashes in the Bario-Ba'Kelalan areas.

Koester, R., Cooper, D. C., Frost, J. R., & Robe, R. Q. (2004). *Sweep width estimation for ground search and rescue* (Task Order No. DTCG32-03-F000012). Retrieved from United States Coast Guard website: http://www.uscg.mil/hq/cg5/cg534/nsarc/DetExpReport_2004_final_s.pdf.

For the first time in history, a scientifically sound yet practical method for objectively determining detection probabilities for objects of importance to search and rescue (SAR) in the land environment was successfully developed and field-tested. Data was collected using volunteer searchers and analyzed with simplified analysis techniques, all at very low cost. This work opens the door for resolving search planning and evaluation issues that have been vigorously debated within the land SAR community for nearly 30 years but never settled. Searching is by its very nature a probabilistic process in which there is no guarantee of either success or failure. Searching remains a significant challenge, especially when lives are at risk. However, a carefully planned search using the right tools and concepts is significantly more likely to succeed and, of equal importance when lives are at stake, succeed sooner. Planning a search consists of evaluating all the available information and then, since it is not

generally possible to do a thorough search everywhere all at once, deciding how to best utilize the available, and often limited, search resources. Since “all available information” also includes any unsuccessful searching already done, a proper accounting is needed for how well each of the various segments or sub-divisions of the general search area have been searched. This becomes an input for planning subsequent search activity for the lost or missing person. For both pre- search planning and post-search evaluation, it is essential that the search planner be able to objectively estimate the probability of detecting a given object in a given segment of the search area with a given resource and level of effort. The probability of detection (POD) is a function of the level of effort, the size of the segment, and how easy or hard it is to detect the object(s) of the search. The ease or difficulty of detection is in turn a function of the sensor in use (usually the unaided human eye), the nature of the object being sought (size, color, etc.), and the environment at the time and place of the search (terrain, vegetation, weather, etc.). While planners of land searches usually know what they are searching for, what resources they have available, and the sizes and environmental characteristics of the segments where resources are to be or have been sent, they have had no way to quantify the ease or difficulty searchers will have in detecting the object of the search. This has left them without an objective method for estimating POD and has effectively thwarted attempts over the past 30 years to put land SAR search planning on a more scientific footing. Planners have been forced to either make subjective POD estimates without reliable data on which to base them, or depend on the even more subjective estimates of the searchers themselves. The simplest metric for quantifying “detectability” is a value called the “effective sweep (or search) width” (ESW). This concept reduces the combined effects of all the factors affecting detection (sensor, environment, search object) in a given search situation to a single number characterizing search object “detectability” for that situation. Effective Sweep Width can be considered a “detectability index” that takes everything into consideration. It should not be thought as the “width” or spacing between sensors. Unfortunately, effective sweep width cannot be measured directly. It is necessary to perform detection experiments and reduce the data from them.

Lewandowski, A., Niehoefer, B., & Wietfeld, C. (2011). Galileo/SAR: Performance aspects and new service capabilities. *International Journal of Satellite Communications and Networking, 29,* 441-460. doi: 10.1002/sat.983

The European satellite navigation system Galileo is a highly promising technology and offers communication capabilities that can be bridled to provide an enhanced Search-and-Rescue (SAR) service in combination with the system, currently in service, Cospas-Sarsat. In order to enhance the process of retrieval during a rescue operation, this article proposes a Short Messaging Service (SMS) by utilizing the existing message formats and owes of the SAR service. Architectural building blocks which are particularly belonging to either Cospas-Sarsat or Galileo are highlighted. A new simulation method for local 3D scenarios is presented, which combines detailed 3D environment models with ray tracing and event-based protocol simulation. Results, both in a global and local 3D setup, reflect the performance indicators of the satellite systems

from which the achievable service quality of SAR-SMS is deduced. The necessity of Galileo/SAR for highly reliable and fast applications in emergency situations is show and a minimum number of Galileo satellites carrying SAR payload is derived.

Lukowski, T. I., & Charbonneau, F. J. (2002). Synthetic aperture radar and search and rescue: Detection of crashed aircraft using imagery and interferometric methods. *Canadian Journal of Remote Sensing, 28(6),* 770-781.

This paper summarizes some results of studies at the Canada Centre for Remote Sensing (CCRS) using Synthetic Aperture Radar (SAR) imagery from spaceborne systems for the detection of crashed aircraft. Studies have been carried out using intensity values only and interferometric methods (using complex image pairs). Change detection using interferometric coherence is particularly promising. The relative size of crashed aircraft and the low resolution of single polarization, single-frequency spaceborne SAR imagery (approximately 9 m ground resolution being the best currently available from operational remote sensing satellites) have been found to limit the use of such imagery, although the techniques themselves show promise. Further study is needed to examine if the better resolutions that will be available from future systems such as RADARSAT-2 make possible the reliable detection of crashed aircraft using the methods examined here.

Mehta, A. (2011, Fall). The international Cospas-Sarsat programme: Taking the "search" out of search and rescue. *The Coast Guard Journal of Safety & Security at Sea: Proceedings of the Marine Safety & Security Council.* Retrieved from http://uscgproceedings.epubxp.com/issue/43475/.

The International Cospas-Sarsat Programme (Cospas-Sarsat) is an intergovernmental organization established to coordinate satellite-aided search and rescue activities. It comprises two satellite-based systems that relay distress signals from mariners, aviators, and land-based users. Russian satellites and instruments comprise the COSPAS system, which is a Russian Acronym for Cosmicheskaya Sistema Poiska Avariynyh Sudov, or "space system for the search of vessels in distress." The search and rescue satellite-aided tracking system, or SARSAT, is the name of a payload on the National Oceanic and Atomospheric Administration's polar-orbiting operational environmental satellites and geostationary operational environmental satellites. The system also includes emergency beacons used to initiate a distress call and ground equipment used to track satellites, retrieve the signals, locate the source of the signal, and transmit the distress alerts to search and rescue organizations. Together, they form Cospas-Sarsat.

Nixon, T. (2007, Summer). Aviation gears up for search and rescue. *The Coast Guard Journal of Safety & Security at Sea: Proceedings of the Marine Safety & Security Council.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/On%20Scene/OSsummer2007.pdf.

This article discusses the United States Coast Guard's New Search and Rescue Capabilities and Technologies.

Richardson, H. R., & Discenza, J. H. (1980). The United States Coast Guard computer-assisted search planning (CASP) system. *Naval Research Logistics Quarterly, 27,* 659-680.

This paper provides an overview of the Computer-Assisted Search Planning (CASP) system developed for the United States Coast Guard. The CASP information processing methodology is based upon Monte Carlo simulation to obtain an initial probability distribution for target location and to update this distribution to account for drift due to currents and winds. A multiple scenario approach is employed to generate the initial probability distribution. Bayesian updating is used to reflect negative information obtained from unsuccessful search. The principal output of the CASP system is a sequence of probability "maps" which display the current target location probability distributions throughout the time period of interest. CASP also provides guidance for allocating search effort based upon optimal search theory.

Schoonmaker, J., Reed, S., Podobna, Y., Vazquez, J., & Boucher, C. (2010). A multispectral automatic target recognition application for maritime surveillance, search and rescue. *Proceedings of the Imagine Sensors and Surveillance Systems II, 7666,* doi:10.1117/12.852651

Due to increased security concerns, the commitment to monitor and maintain security in the maritime environment is increasingly a priority. A country's coast is the most vulnerable area for the incursion of illegal immigrants, terrorists and contraband. This work illustrates the ability of a low-cost, light-weight, multi-spectral, multi-channel imaging system to handle the environment and see under difficult marine conditions. The system and its implemented detecting and tracking technologies should be organic to the maritime homeland security community for search and rescue, fisheries, defense, and law enforcement. It is tailored for airborne and ship based platforms to detect, track and monitor suspected objects (such as semi-submerged targets like marine mammals, vessels in distress, and drug smugglers). In this system, automated detection and tracking technology is used to detect, classify and localize potential threats or objects of interest within the imagery provided by the multi-spectral system. These algorithms process the sensor data in real time, thereby providing immediate feedback when features of interest have been detected. A supervised detection system based on Haar features and Cascade Classifiers is presented and results are provided on real data. The system is shown to be extendable and reusable for a variety of different applications.

Soylemez, E. (2007). *GIS-based search theory application for search and rescue planning.* (Unpublished master's thesis). Middle East Technical University, Ankara, Turkey.

Search and Rescue (SAR) operations aim at finding missing objects with minimum time in a determined area. There are fundamentally two problems in these operations. The first problem is assessing highly reliable probability distribution maps, and the second is determining the search pattern that sweeps the area from the air as fast as possible. In this study, geographic information systems (GIS) and multi criteria decision analysis (MCDA) are integrated and a new model is developed based upon Search Theory in order to find the position of the missing object as quickly as possible with optimum resource allocation. Developed model is coded as a search planning tool for the use of search and rescue planners. Inputs of the model are last known position of the missing object and related clues about its probable position. In the developed model, firstly related layers are arranged according to their priorities based on subjective expert opinion. Then a multi criteria decision method is selected and each data layer is multiplied by a weight corresponding to search expert's rank. Then a probability map is established according to the result of MCDA methods. In the second phase, the most suitable search patterns used in literature are applied based on established probability map. The developed model is a new approach to shortening the time in SAR operations and finding the suitable search pattern for the data of different crashes.

Thomas, L. C., & Hulme, P. B. (1997). Searching for targets who want to be found. *Journal of the Operational Research Society, 48,* 44-50.

The paper reports some simulation results for models of the types of search that might be conducted by a rescue helicopter when looking for a walker who is lost in the desert and wants to be found. The walker has a smaller speed than the helicopter, but the walker can detect the helicopter at a greater distance than the helicopter can detect the walker. Possible search strategies include those in which the helicopter flies in a decreasing spiral or sweeps back and forth across a region. The walker may remain stationary, move randomly or walk towards the helicopter when he hears it. Simulation work suggests the types of strategies that may do best.

Toet, A. (2002). Detection of dim point targets in cluttered maritime backgrounds through multisensory image fusion. In W. Watkins, D. Clement & W. Reynolds (Eds.), *SPIE Conference, Targets and Backgrounds VIII: Characterization and Representation: Vol. 4718*. Orlando, FL.

Multispectral IR imaging techniques are frequently deployed in maritime operations, for instance to detect floating mines or to find small dinghies and swimmers during search and rescue operations. However, maritime backgrounds usually contain a large amount of clutter that severely hampers the detection of dim point targets. Here we present a simple algorithm that deploys the correlation between target signatures in two different (3-5 and 8-12 ìm) IR frequency bands to reduce the amount of clutter. First, both individual IR bands are filtered with a morphological opening top-hat transform to extract small details. Second, the resulting detail images are thresholded to produce binary detail images, representing potential target areas. Third, a fused detail

image is obtained by taking the intersection (logical AND) of both binary IR detail images. Details that appear in both IR bands remain in this fused detail image, whereas a large fraction of uncorrelated noise details is filtered out. Remaining noise details can be removed by taking into account the temporal characteristics of the target signatures and by using a priori knowledge of structure of the scene and the size of potential targets. The method is tested on two image sequences showing a maritime scene with three kayaks approaching from far away. The scenario was registered in the 3-5 Pm and 8-12 Pm IR frequency bands, and in the visual range. The results show that the proposed multispectral processing technique has the potential to improve the detection of dim point targets in cluttered maritime backgrounds.

Vidan, P., Kasum, J., & Jolic, N. (2010). A proposal for the models and measures of search and rescue on inland waterways. *Transport, 25(2),* 178-185. doi: 10.3846 / transport.2010.22

Search and rescue on inland waterways are considered to be insufficiently developed. The methods of search and rescue have been developed only for sea waterways. Despite the possibilities of comparison, the specific characteristics of inland waterways are the reason why it is seriously considered to develop proposals for search and rescue models on inland waterways. The authors of this paper suggest a search and rescue model for rivers, lakes and channels regarding configuration and the current safety conditions on inland waterways. The model allows a successful quest for reduced search time. In addition, the model predicts the performance of the search.

Vincent, E. (2006). *Measures of effectiveness for airborne search and rescue imaging sensors.* (Report No. TM 2005-301). DRDC Valcartier, QC.

This study identifies the relevant measures of effectiveness for the evaluation of airborne imaging sensors to be used in search and rescue operations. This is done with a view to preparing flight trials for a sensor system to be developed under the Advanced Integrated Multi-sensing Surveillance (AIMS) Technology Demonstration Project. This system will consist of a thermal imager and an active range-gated camera integrated within a single stabilized platform, and will be designed to improve the ability to locate a variety of targets from aircraft despite low-visibility conditions. The approach proposed for the development of the measures of effectiveness is to partition the time required for finding search objects and to extract the measures from each resulting segment. The main measures of effectiveness identified are probability of detection, rate of false positive generation, and time required to recognize and identify targets.

Wallace, R. G., Affens, D. W., & Rais, H. (1997, April). *Beaconless search and rescue overview – history, development, and achievements.* Paper presented at the meeting of SAR Application of Search and Rescue I, Orlando, FL. doi:10.1117/12.277101

The NASA Search and Rescue Mission at Goddard Space Flight Center (GSFC) is carrying out a technology development project intended to complement the COSPAS-

SARSAT satellite-based distress alerting and locating system. This system is based on emergency radio beacons and cannot function when beacons fail to operate. The beaconless search and rescue concept utilizes an airborne or spaceborne remote sensing instrument, such as a synthetic aperture radar (SAR), to aid in searching for downed aircraft in remote regions when no beacon is present. Compared with conventional visual search, a radar-based system would be capable of dramatically improving crash site detection due to its wide area coverage and foliage penetration. Moreover, the performance of this system is unaffected by weather conditions and ambient light level and hence it offers quick response time which is vital to the survival of crash victims. The Search and Rescue Mission has conducted a series of field experiments using the Jet Propulsion Laboratory's airborne SAR system (AIRSAR) which has demonstrated the technical feasibility of using SAR. The SAR data processing software (SARDPS) developed at GSFC is used to produce high-quality SAR images for post-processing and analysis. Currently various elements of an operational system are being investigated, including a SAR designed specifically to meet search and rescue needs, real-time or near-real time on-board SAR processing, and processing algorithms for advanced automatic crash site detection, image geo-rectification and map registration.

Washburn. A. R. (1983). Search for a moving target: The FAB algorithm. *Operations Research, 31(4),* 739-751.

We propose and study an iterative Forward And Backward (FAB) algorithm applicable to the problem of computing optimal search plans when the target's motion is modeled by a discrete space and time Markov chain. This paper generalizes the class of objective functions to which the method applies.

Westall, P., Carnie, R. J., O'Shea, P., Hrabar, S., Walker, R. A. (2007, March). *Vision-based UAV maritime search and rescue using point target detection.* Paper presented at the twelfth meeting of the Australian International Aerospace Congress, Brisbane, Australia.

Human maritime search and rescue missions have always been challenging and an element of chance is involved in the detection of survivors at sea. This research is proposing the use of machine vision to assist UAVs to increase the chances of success in locating humans lost at sea. This paper presents an application of current image processing methods for target detection in a synthetic maritime scenario. An evaluation of the algorithm's performance is also provided. The difficulties faced in the automatic detection of human targets in a maritime search environment are also considered. The paper concludes that there is a range of greyscale intensities, approximately 26% based on current data set, where the target was unable to be detected which may limit the applicability of the algorithm. The effect on performance of target intensity level, threshold, t, and forgetting factor, α, are also investigated.

Wollan, H. (2004). *Incorporating heuristically generated search patterns in search and rescue.* (Unpublished master's thesis). University of Edinburgh, Edinburgh, Scotland.

Search and Rescue operations rely heavily on generic search patterns when using aircraft in a search effort. These search patterns need to be manually modified to accommodate the area to be searched. This dissertation proposes to use heuristic methods to generate search patterns to fit the area instead of modifying a generic pattern. With this aim in mind, this dissertation describes an implementation of one such heuristic method in a Search Management tool. This Search Management tool incorporates the ability to view and maintain the status of a search effort along with the search pattern generation. These functionalities provide a tool to use throughout a search effort to define the search area, generate the search patterns as necessary, and view the current status of the search effort. Additionally this Search Management tool includes the capability for XML messaging, allowing users in the field to send updated information to the search manager through the Search Management tool.

3.3 Response Posture and Other Timeline Studies

Adams, A. L., Schmidt, T. A., Newgard, C. D., Federiuk, C. S., Christie, M., Scorvo, S. & DeFreest, M. (2007). Search is a time-critical event: When search and rescue missions may become futile. *Wilderness & Environmental Medicine, 18(2),* 95-101. doi: 10.1580/06-WEME-OR-035R1.1

Objectives: The purpose of this study was to derive and validate a rule for duration of search (ie, search time) that maximizes survivors and after which a search and rescue (SAR) mission may be considered for termination. **Methods:** This was a retrospective cohort study of all SAR missions initiated in Oregon over a 7-year period, which were documented in a population-based administrative database. The following types of search missions were excluded from analysis: redundant reports of a single search; lost helicopters and airplanes; support of organized events; law-enforcement searches; searches for persons actively avoiding rescue; body recovery missions; and cases without outcome information. The cohort was divided into a derivation cohort (searches from 1997–2000) and a validation cohort (2001–2003). The primary outcome was survival. Variables considered in the model included age, gender, minimum and maximum daily temperatures, precipitation, search time, and whether the search involved an air or water incident. Missing data were handled using multiple imputation. Classification and regression tree (CART) methods were used to derive the model. **Results:** The derivation cohort included 1040 searches involving 1509 victims, 70 (4.6%) of whom died. The validation cohort included 1262 searches involving 1778 victims; 115 (6.5%) died. Search time was the only variable retained in the final model, with a cut-point of 51 hours. The derivation model was 98.9% sensitive; the same model run using the validation cohort was 99.3% sensitive. **Conclusions:** This time-based model may aid search managers in the decision about starting a search or changing search tactics for missing persons.

Frost, J. R. (2001). *Review of search theory: Advances and applications to search and rescue decision support* (Research Report No. R&DC 554). Retrieved from Defense Technical Information Center website: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA397065&Location=U2&doc=GetTRDoc.pdf

Fundamental limitations inherent in manual search planning methods have severely limited the application of advances in several areas that could improve the efficiency and effectiveness of the U.S. Coast Guard's search and rescue mission. These areas include advances in search theory, environmental data products, knowledge of detection profiles for various sensors, and knowledge of leeway behavior. The U.S. Coast Guard's computerized search planning aids have not kept up with advances in these areas or with technology in general. This report reviews the history and recent advances of search theory and its application to a variety of search problems. It then reviews the history of the U.S. Coast Guard's search planning methods, showing where search theory was initially applied, albeit in a necessarily very limited way, and where later modifications departed from the theoretical basis of the original methodology. Several computerized search planning decision support tools are analyzed and compared, as are the differences between an analytic approach and a simulation approach. The results are summarized in a matrix. The U.S. Coast Guard needs a new search planning decision support tool for search and rescue and other missions. This tool should use the simulation approach due to its power and flexibility as compared to analytic techniques.

Giang, W., & Keillor, J. (2009). Effects of cue saliency in an assisted target detection system for search and rescue. *Proceedings of the Science and Technology for Humanity (TIC-STH), International Conference, Toronto, Canada,* 527-532.

Assisted target detection (ATD) systems are designed to support operators in complex visual search tasks by determining areas within the visual scene that have a higher probability of containing a target. These locations must somehow be conveyed to the operators via a human-machine interface, and little work has been done on the design of the cues themselves. The type of visual cue may affect search performance and visual scan paths, and if operators find that an ATD system disrupts their performance of the task they will not use the system. In order to investigate the effects of cue saliency on operator performance, a circular translucent cue with two levels of brightness was tested in a simulated search and rescue task. Despite the use of cues that had a relatively low reliability, both types of cues resulted in improved detection performance. There was an effect of cue brightness such that brighter cues were most advantageous when there were fewer cues in the scene. Varying characteristics of the visual cues were observed to have an impact on how the operator scans the scene.

Glenn, S. M., Dickey, T. D. Parker, B., & Boicourt, W. (2000). Long-term real-time coastal ocean observation networks. *Oceanography, 13(2),* 24- 34.

Oceanographers are well acquainted with the challenges of working in an undersampled ocean. Observations are often sparse, difficult or expensive to acquire, and may not even be available to the sea-going scientist until they have physically reached their study site by boat. Much is often left to chance if the scientist's interests lie in the study of episodic events that may be short lived in time and distributed in space. At the other end of the spectrum, scientists studying long-term trends, such as the coastal and estuarine response to global climate change or local human influences, must be able to separate natural variability from anthropogenic effects. This can only be accomplished through the analysis of long-term time series of key parameters obtained from permanent observation stations. Our ability to both capture short-lived episodic events and resolve long-term trends in the coastal ocean is rapidly improving through technological advances in sensors and observation platforms envisioned in the early 1990s and brought to fruition later in the decade. Observation networks consisting of remote sensing, stationary, movable and drifting platforms are being assembled throughout the country. Modern communication systems provide a means for the platforms to report their observations in real time, and the World Wide Web provides a means for wide-spread instantaneous distribution. The use of numerical models to assimilate diverse datasets and forecast forward in time is now well accepted. The combined use of real-time observations and model forecasts to improve observational efficiency has spawned the new field of adaptive sampling. Emerging partnerships between scientists and engineers from academia, government and private industry are tackling the new developmental challenges that now include autonomous platforms, system integration, and automated response scenarios. In this paper, we first discuss the current rationale for coastal observing systems, including both real-time and long-term applications. We then focus on the enabling technologies prompting the rapid proliferation, and the new sensors and platforms available on the near horizon that will improve their capabilities. We conclude with a common set of problems and limitations, and with recommendations for the future. **Application to Search and Rescue:** Search and Rescue (SAR) is one of the Coast Guard's oldest missions. Approximately 95% of their SAR responses occur within 20 nautical miles of the coast, with 20% lasting longer than 24 hours. Because of the urgency of SAR, ongoing real-time observations and short-term forecasts for the coastal ocean would help reduce the search time, resulting in more lives saved, reduced costs, and fewer Coast Guard personnel placed at risk.

Haagensen, R., Sjoborg, K., Rossing, A., Ingilae, H., Markengbakken, L., & Steen, P. (2004). Long-range rescue helicopter missions in the Arctic. *Prehospital and Disaster Medicine, 19(2),* 158-163.

Background: Search and rescue helicopters from the Royal Norwegian Air Force conduct ambulance and search and rescue missions in the Barents Sea. The team on-board includes an anaesthesiologist and a paramedic. Operations in this area are challenging due to long distances, severe weather conditions, and arctic winter darkness. **Methods**: One-hundred, forty-seven ambulance and 29 search and rescue missions in the Barents Sea during 1994–1999 were studied retrospectively with special

emphasis on operative conditions and medical results. **Results and Discussion**: Thirty-five percent of the missions were carried out in darkness. The median time from the alarm to first patient contact was 3.3 hours and the median duration of the missions was 7.3 hours. Forty-eight percent of the missions involved ships of foreign origin. Half the patients had acute illnesses, dominated by gastrointestinal and heart diseases. Most of the injuries resulted from industrial accidents with open and closed fractures, amputations, and soft tissue damage. Ninety percent of the patients were hospitalized; 7.5% probably would not have survived without early medical treatment and rapid transportation to a hospital. **Conclusion:** Using a heavy search and rescue helicopter in the Barents Sea was the right decision in terms of medical gain and operative risk.

Lau, H., Huang, S., & Dissanayake, G. (2005). Optimal search for multiple targets in a built environment. *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems,* 228-233.

The main contribution of this paper is an algorithm for autonomous search that minimizes the expected time for detecting multiple targets present in a known built environment. The proposed technique makes use of the probability distribution of the target(s) in the environment, thereby making it feasible to incorporate any additional information, known a-priori or acquired while the search is taking place, into the search strategy. The environment is divided into a set of distinct regions and an adjacency matrix is used to describe the connections between them. The costs of searching any of the regions as well as the cost of travel between them can be arbitrarily specified. The search strategy is derived using a dynamic programming algorithm. The effectiveness of the algorithm is illustrated using an example based on the search of an office environment. An analysis of the computational complexity is also presented.

Shokri, M., Tizhoosh, H. R., & Kamel, M. S. (2009). Oppositional target domain estimation using grid-based simulation. *Applied Soft Computing, 9,* 423-430.

In this paper we address the problem of estimating the target domain for search and navigation problems. We propose oppositional target domain estimation by modeling the search and navigation environment as a grid. Typically real-world applications exhibit an environment that is extremely large, dramatically diminishing the usability of intelligent agents for search and navigation. The reduction of the size of environment, hence, can help to increase the efficiency and applicability of the agents. We address this issue by modeling the environment as a grid and estimating the target domain inside the environment. The target domain is a reduced space which includes the target. The proposed technique is specifically concerned with reducing the environment using the concept of opposition. Experimental results show significant reduction of the environment size resulting in a shorter search time.

3.4 Strategic Policy

Bleakney, E. M. (2009). *Finding the "sweet spot" for catastrophic incident search and rescue.* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA.

This thesis examines the national preparedness to conduct catastrophic incident search and rescue (SAR) using organization-specific doctrine, concept plans, congressional research reports and testimonies, after action reviews, periodicals, federal government plans, interviews, a focus group and two benchmark studies. The research indicates that individual organizations conduct SAR activities well, but combined, joint and interagency catastrophic search and rescue preparations are lacking. Should another catastrophic incident occur tomorrow, the SAR results will likely exhibit the same unacceptable inefficiency as was found in Hurricane Katrina. Finding the sweet spot for response to catastrophic incidents is needed. There are three major findings: First, a national strategy for SAR is needed. This epic effort will help to improve the interagency coordination between equity holders of the search and rescue megacommunity and set the conditions to improve catastrophic incident SAR. Secondly, a Joint Air Ground Coordination Center (JAGCC) is critical to effective response operations. Two benchmark studies suggest a framework for developing a SAR coordination center using experiences of the wildland firefighting community and the United States Secret Service. Finally, domestic and international interagency coordination through integrated strategy development, planning, training and exercises is needed to improve response operations.

Chase, E. T., (2000). *Cost and operational effectiveness analysis of alternative force structures for fulfillment of the United States Marine Corps operational support airlift and search and rescue missions* (Unpublished master's thesis). Naval Postgraduate School, Monterey. CA.

This thesis provides a preliminary cost and operational effectiveness analysis of alternative force structures for the United States Marine Corps operational support airlift and search and rescue missions. The four alternative force structures include C-12s and CH-46Es, C-35s and CH-46Es and HV-609s. Lifecycle cost analysis of the alternative force structures using Crystal Ball forecasting provides a 90% upper confidence level lifecycle cost estimate that identifies a mix of C-35s for operational support airlift and CH-46Es for search and rescue as the least expensive alternative. Operational effectiveness analysis provides a measure of overall utility for each of the four alternative force structures based on five measures of effectiveness. The measures of effectiveness examined are air travel time, total travel time, landing site requirements, range versus time on station, and payload versus range. Analytical hierarchy process rankings indicate that the HV-609 is the preferred alternative considering these measures of effectiveness. Analysis of cost versus operational effectiveness identifies the HV-609 as the most cost and operationally effective alternative for fulfilling the Marine Corps operational support airlift and search and rescue missions.

Imray, M., Leslie, T., Kissmann, P., Keillor, J., Erdos, R., & Paraschivoiu, D. (2010). *Review of the statement of operational requirement for the fixed wing search and rescue aircraft* (Report No. CR-FRL-2010-0025). Retrieved from Department of National Defence site: http://www.forces.gc.ca/site/pri/2/_doc/Review_of_SOR_for_FWSAR_-_Final_Report_Submitted_by_DGIAR.pdf.

Background: The existing Fixed Wing Search and Rescue (FWSAR) capability is currently provided by two fleets of ageing aircraft. The Department of National Defence (DND) has produced a Statement of Operational Requirement (SOR) to acquire modern, effective replacement FWSAR aircraft to provide the capability for thirty years. The Department of Public Works and Government Services Canada (PWGSC) contracted the National Research Council Canada (NRC) under a Memorandum of Understanding (MoU) to conduct an independent review of the SOR. **Assumptions, Constraints and High Level Mandatory Capability Requirements:** This report documents a review of the assumptions and constraints used to derive the fifteen High Level Mandatory Capability (HLMC) requirements followed by a review of each HLMC as they are presented in the FWSAR SOR. NRC has provided qualitative assessments and, in some cases, specific recommendations for each assumption, constraint and HLMC requirement. **Principal conclusions:** The SOR as written is over constrained. Stated mission scenarios, preservation of the status quo regarding standby posture, CF crewing, and the four existing main operating bases may limit the potential number of solutions industry could propose. The stated objective of the SOR is that new FWSAR aircraft provide a level of service to Canadians equal to that currently provided; a level that is not currently defined in Government of Canada policy. An aircraft compliant with the SOR as written may not achieve the above objective. **Recommendations:** A principal recommendation is that the SOR be amended to better reflect a capability based requirements rationale rather than a platform centric approach. The capabilities required should not refer explicitly to those provided by existing DND FWSAR fleets. The SOR should describe the FWSAR capability sought by the Government of Canada in terms of SAR service to Canadians. It should also include a list of mandatory requirements reflecting the nature of service to be delivered and the timely delivery of this service. The SOR should also include a minimum list of constraints on any proposals. This document provides recommendations regarding the list of mandatory requirements and constraints. NRC recommends that the FWSAR SOR be amended in light of the review documented herein.

Norrington, L., Quigley, J., Russel, A., & Van der Meet, R. (2008). Modelling the reliability of search and rescue operations with Bayesian Belief Networks. *Reliability Engineering and System Safety 93,* 940-949. doi:10.1016/j.ress.2007.03.006

This paper uses a Bayesian Belief Networks (BBN) methodology to model the reliability of Search And Rescue (SAR) operations within UK Coastguard (Maritime Rescue) coordination centres. This is an extension of earlier work, which investigated

the rationale of the government's decision to close a number of coordination centres. The previous study made use of secondary data sources and employed a binary logistic regression methodology to support the analysis. This study focused on the collection of primary data through a structured elicitation process, which resulted in the construction of a BBN. The main findings of the study are that statistical analysis of secondary data can be used to complement BBNs. The former provided a more objective assessment of associations between variables, but was restricted in the level of detail that could be explicitly expressed within the model due to a lack of available data. The latter method provided a much more detailed model, but the validity of the numeric assessments was more questionable. Each method can be used to inform and defend the development of the other. The paper describes in detail the elicitation process employed to construct the BBN and reflects on the potential for bias.

National Search and Rescue Committee (2007). *National search and rescue plan of the United States.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/manuals/Natl_SAR_Plan(2007).pdf.

This is one of three primary documents orienting the strategic and operational effort of the National Search and Rescue Community (NSARC) and Search and Rescue (SAR) megacommunity. The other two documents are the International Aeronautical SAR (IAMSAR) manual, Volumes 1 – 3 and the U.S. National SAR Supplement to the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual. Out of these three documents arise responsibilities for SAR that are accomplished, not only by the NSARC but also by other federal, state, territorial, tribal and local (FSTTL) agencies, including the Department of Defense.

National Search and Rescue Committee (2008). *National search and rescue supplement to the international aeronautical and maritime search and rescue manual.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/manuals/Natl_SAR_Supp.pdf.

This is one of three primary documents orienting the strategic and operational effort of the National Search and Rescue Community (NSARC) and Search and Rescue (SAR) megacommunity. The other two documents are the International Aeronautical SAR (IAMSAR) manual, Volumes 1 – 3 and the National Search and Rescue Plan of the United States to the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual. Out of these three documents arise responsibilities for SAR that are accomplished, not only by the NSARC but also by other federal, state, territorial, tribal and local (FSTTL) agencies, including the Department of Defense.

Palm, J., & Tornqvist, E. (2008). Governing the sea rescue service in Sweden: Communicating in networks. *Journal of Risk Research, 11(1-2),* 269-280.

This paper discusses how various actors communicate about and coordinate sea rescue activities in networks. We combine a network approach with theories of inter-organization communication to understand how communication can facilitate or limit

coordination in networks. Search and rescue officers retain the overall authority to direct rescue missions, and coordination with several other professions is central to this. When coordinating different professional actors in a network it is important to develop trust, legitimacy, and a shared and uniform understanding of the situation and of how to act. Communication deficiencies often result from the fact that involved actors belong to different organizations with different cultures or representing different professions. The greatest gap we found was between those working and not working at sea, and between those habitually or seldom involved in rescue activities. Communication comprises more than simply exchanging information; it also entails the forging of relationships, to facilitate future coordination and cooperation and to develop mutual trust and understanding. In any rescue operation it is important that the actors interpret communication in the same way and act according to a shared pattern. Joint training and follow-up are important conditions for continuous learning and development in this regard.

Russell, W. (2011). *A proposed arctic search and rescue strategy for Canada* (Unpublished master's thesis). Dalhousie University, Halifax, NS.

The Canadian Arctic has experienced a notable increase in maritime activity in recent years, driven in part by increased accessibility due to environmental changes as well as a growing northern cruise industry and hydrocarbon and mineral extraction projects. The present and expected future expansion of these activities has prompted concerns regarding the provision of northern government services, in particular the lack of Search and Rescue (SAR) infrastructure within the Arctic. To this end, the *Agreement on Cooperation on Aeronautical and Maritime Search and Rescue* (ASAR) was signed at the 2011 Ministerial Meeting of the Arctic Council, requiring member states to establish an "adequate and effective search and rescue capability" (Arctic Council, 2011). Drawing upon the requirements of the recently signed ASAR Agreements, supported by a discussion regarding future northern activity projections and considerations from past Arctic SAR incidents, this study provides recommendations for a SAR strategy for the Canadian Arctic. Elements addressed include the absence of effective Strategic Management Plan for Canadian SAR, community initiatives and a discussion regarding the levels of service for SAR within the Arctic.

3.5 Tactics and Procedures

Abi-Zeid, I., Nilo, O., Schvartz, S., & Morin, M. (2010). Towards a knowledge-based system prototype for aeronautical search and rescue operations. *Proceedings of the 13th International Conference on Information Fusion, Edinburgh, Scotland,* 1-8.

The long-term objective of our project is to develop a knowledge-based tool for Search and Rescue (SAR) operations to support a Canadian search mission coordinator in determining the likely location of a missing aircraft overland. In order to attain this objective, we used a knowledge engineering approach to acquire, structure

and model SAR experts' knowledge. This knowledge was modeled and implemented in a knowledge-based system prototype. The input to the interactive prototype consists of the known information regarding a given SAR case. Its main output is a set of scenarios describing the various hypotheses on what might have happened to the missing aircraft, why and where, the plausible routes followed, as well as the possibility area, defined as the region most likely to contain the missing aircraft. In this paper, we introduce the knowledge model, present an application example and briefly describe the prototype.

Allen, A. (2011, Spring). CG moves to a new survival model. *The Coast Guard Journal of Safety & Security at Sea: Proceedings of the Marine Safety & Security Council.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/On%20Scene/OSspr11.pdf.

The U.S. Coast Guard Research and Development Center working with the U.S. Army Research Institute of Environmental Medicine (USARIEM) in Natick, Massachusetts, developed the Probability of Survival Decision Aid (PSDA) for the Coast Guard. The PSDA model has replaced CESM, the Cold Exposure Survival Model as the Coast Guard's primary source for search and rescue survival decision support.

Allen, A. (2006, Fall). Survival modeling and SAROPS. *The Coast Guard Journal of Safety & Security at Sea: Proceedings of the Marine Safety & Security Council.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/On%20Scene/OSFall06.pdf.

The principle role of search planning tools is to provide guidance on optimally allocating the search resources. "Optimal" is traditionally defined in terms of maximizing the Probability of Success (POS) for finding search objects rather than survivors. The assumption, of course, has been that the search objects will either be or contain survivors. However, the Coast Guard's present search planning tools do not account for survival times – victims are assumed to live forever. Neither are survival times considered in the allocation of resources. In effect, the "Probability of Survival" is set and held constant at 1.0 (100%). Under this assumption, POS is maximized by achieving the optimal balance among the size, track spacing, orientation and location of the search patterns. All with respect to the probability density distribution describing where the search object is more likely and less likely to be while SRUs are on scene searching, and within the constraints imposed by the SRUs' search speeds and on scene endurances. Optimizing in this fashion does not account for those situations where survival times may be limited to only hours or days. Therefore a more appropriate way to define POS for SAR is: The probability of finding survivors and the desired output of search planning methods and tools is optimal survivor search plans. This is a goal for future versions of the Coast Guard's new SAR planning tool, Search and Rescue Optimal Planning System (SAROPS).

Barott, J. B., Gluch, D. P., & Kirby S. L. (2011). Predictive engineering of an unmanned aerial system (UAS) using the architecture analysis and design language

(AADL). *Systems Conference (SysCon), Montreal, Canada,* 569-573. doi: 10.1109/SYSCON.2011.5929086

In this paper, we describe the results of applying predictive software-dependent system engineering practices using the SAE International Architectural Analysis and Design Language (AADL) in the modeling and analysis of an unmanned aerial system (UAS), part of a search and rescue (SAR) system. The SAR system embodies many of the challenges associated with engineering complex software-dependent systems, such as achieving stringent performance requirements and ensuring effective resource utilization. The results of this work demonstrated that model-based software system engineering practices employing the AADL can be used to analyze important system aspects early in architectural development, and can be an integral element in making informed decisions throughout an engineering effort.

Cooper, D. C., Frost. J. R., & Robe, Q. R. (2003). *Compatibility of land SAR procedures with search theory* (Research Report No. unknown). Retrieved from Defense Technical Information Center website: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA511658

The widely-accepted science of search theory as described by Koopman (1946, 1980), Stone (1989) and others was incorporated into the first edition of the National Search and Rescue Manual in 1959 after the U. S. Coast Guard provided the first comprehensive application to civil SAR in the 1950s. Applied search theory quickly gained acceptance by maritime SAR agencies worldwide and has remained in global use ever since. Various practical improvements and modifications to search planning techniques and data have been made over the years, but the application of the underlying theory remains unchanged, as shown in the International Aeronautical and Maritime Search and Rescue Manual (IAMSAR Manual, 1999) and recognized globally as the standard text on aeronautical and maritime SAR operations and methods. After a preliminary review of the available land search planning literature at a special meeting of the National Search and Rescue Committee (NSARC) Research and Development (R&D) Working Group in March of 2001, it was determined that the results of scientific operations research as it relates to searching may not have been effectively applied by those working in land search. In partial response to this, the NSARC R&D Working Group tasked Potomac Management Group, Inc., with reviewing current published methods used for searching areas for lost, missing, or distressed persons on land who are in need of assistance. The purpose was to gain familiarity with current terminology and procedures, and to identify which procedures are compatible with the application of formal search theory to land search, which could become compatible with practical revisions, and which cannot be revised in a practical manner to achieve compatibility. The findings of this review are included in this report. This report concludes that it does not appear there has ever been a comprehensive attempt to apply the science of search theory to the development of land search planning and techniques. The report finds that various individuals at various times have attempted to apply bits and pieces of what

they believed to be search theory to the problem. There is clearly a great deal of room for improvement as search theory can make substantial contributions if properly applied. There is also a critical need to rectify some of the more crucial misunderstandings that could have a significantly detrimental effect on future inland search operations.

This report recommends the following:

1. Developing a standard methodology for land search planning.
2. Refining and validating the procedures for establishing land sweep width values.
3. Performing sweep width experiments for the land SAR environment.
4. Developing computer-based search planning decision support tools for land SAR.
5. Developing improved resources allocation guidance for area land searches.
6. Improving procedures for estimating POD on land.

Marven, C. A., Canessa, R. R., & Keller, P. (2007). Exploratory spatial data analysis to support maritime search and rescue planning. In J. Li, S. Zlatanova, & Fabbri, A (Eds.), *Geomatics Solutions for Disaster Management* (pp. 271-288). doi 10.1007/978-3-540-72108-6_18

Managers are often expected to analyze, report, plan, and make decisions using data that are aggregated to administrative areas historically delineated for other purposes. This enforced aggregation may misinterpret true patterns or complexities underlying the data, hindering recognition and communication of potentially important insights. The result may well provide misleading information on which to base decisions. Spatial data analysis tools are available that could allow managers to analyze and aggregate data more meaningfully and effectively for decision-making and planning, while still allowing them to report to the standard administrative units. These spatial analytical tools would be of importance to managers who are using data to prevent, plan for, or mitigate risk-related events. The Canadian Coast Guard is offered as an example whereby managers are responsible for planning for the provision of maritime search and rescue emergency response using historical maritime incident data collected site-specific but aggregated to historical reporting units. We explore how spatial data analysis techniques, in combination with GIS, can provide a way to analyze incident data spatially regardless of existing reporting units, providing a better way to ‘package’ the data for use in emergency response planning and decision-making. We show how marine incident patterns over the region can be monitored to help planners anticipate emerging incident hot-spots or gauge the persistence of existing hot-spots. Finally, we show how a better understanding of incident patterns within existing administrative units can inform the development of new reporting boundaries that better reflect incident patterns.

McKay, K. N., & Laube, J. (1988). Search and rescue: A case study of design flexibility. In M. Abrams, P. Haigh & J. comfort (Eds.), *Proceedings of the 1988 Winter Simulation Conference* (pp. 381-388). San Diego, USA.

This paper is a case study description of the major techniques used in the design of a Search and Rescue (SAR) model, how the methods contribute to flexibility, and how these software engineering principles relate to a formal methodology (Ziegler, 1987) that has been proposed specifically for simulation development. The techniques described in this paper can be used with any of the common simulation languages (e.g., SIMAN, GPSSH, SLAM II, and SIMSCRIPT II.5).

Kratzke, T. M., Stone, L. D., & Frost, J. R. (2010). Search and rescue optimal planning system. *Proceedings of 13th International Conference on Information Fusion,* 26-29 July 2010, Edinborough, UK

In 1974 the U.S. Coast Guard put into operation its first computerized search and rescue planning system CASP (Computer-Assisted Search Planning) which used a Bayesian approach implemented by a particle filter to produce probability distributions for the location of the search object. These distributions were used for planning search effort. In 2003, the Coast Guard started development of a new decision support system for managing search efforts called Search and Rescue Optimal Planning System (SAROPS). SAROPS has been operational since January, 2007 and is currently the only search planning tool that the Coast Guard uses for maritime searches. SAROPS represents a major advance in search planning technology. This paper reviews the technology behind the tool.

Perry, R. W. (2003). Incident management systems in disaster management. *Disaster Prevention and Management, 12(3),* 405-412. doi: 10.1108/09653560310507226

Particularly since the 11 September terrorist attacks in the USA, much attention has been given to the development and implementation of incident management systems (IMS). The IMS is a tool for marshalling pre-identified and pre-assembled resources to respond to an emergency or disaster. IMS is particularly useful when personnel and resources from many agencies and jurisdictions are required to manage large incidents successfully. While many IMS have been devised over the years, their use remains intermittent. This paper traces the evolution of IMS, reviews how it can be integrated into jurisdictional emergency and disaster management, and specifies the structures that are used in most incident management systems at the municipal level.

Rauschert, I., Agrawal, P., Fuhrmann, A., Brewer, I. Wange, H., Sharma, R., Cai, G., & MacEachren, A. (2002). Designing a human-centred, multimodal GIS interface to support emergency management. *Proceedings of the 10th ACM Symposium on Advances in Geographic Information Systems, USA,* 119-124.

Geospatial information is critical to effective, collaborative decision-making during emergency management situations; however conventional GIS are not suited for multi-user access and high-level abstract queries. Currently, decision makers do not always have the real time information they need; GIS analysts produce maps at the request of individual decision makers, often leading to overlapping requests with slow delivery times. In order to overcome these limitations, a paradigm shift in interface design for GIS is needed. The research reported upon here attempts to overcome analyst-driven, menu-controlled, keyboard and mouse operated GIS by designing a multimodal, multi-user GIS inter-face that puts geospatial data directly in the hands of decision makers. A large screen display is used for data visualization, and collaborative, multi-user interactions in emergency management are supported through voice and gesture recognition. Speech and gesture recognition is coupled with a knowledge-based dialogue management system for storing and retrieving geospatial data. This paper describes the first prototype and the insights gained for human-centered multimodal GIS interface design.

Rodriguez-Rodriguez, A., & Aleman-Flores, M. (2001).A framework for the search and rescue domain. *Proceedings of the 14th International Conference on Applications of Prolog,* 305-316.

We describe the software environment that has been developed for the management and support of planning missions in the SAR domain. We have chosen to develop a configurable environment that simplifies the decision making process to the RCC staff. We also discuss the relation of this project with the Knowledge Management activities, especially with respect to the functions of knowledge creation, compilation, dissemination and application. We consider SARPA as a valuable tool that facilitates the organization to pursue the goals of success and efficiency.

Schvartz, S., Abi-Zeid, I., & Tourigny, N. (2007). Knowledge engineering for modelling reasoning in a diagnosis task application to search and rescue. *Canadian Journal of Administrative Sciences, 24(3),* 196-211.

This paper pertains to the application of knowledge engineering methods to aeronautical search and rescue in Canada. We modelled at the knowledge level the reasoning process of a search mission coordinator when conducting a diagnosis task to determine the routes likely followed by an aircraft missing overland. Knowledge engineering allowed us to develop a reasoning model based on documents and on interviews with domain experts. Our study was conducted in the CommonKADS knowledge modelling framework. The proposed model was validated by domain experts and implemented in a rule-based prototype

Sukthankar, G., Sycara, K. P., Giampapa, J. A., Burnett, C., & Preece, A. (2007). *Towards a model of agent-assisted team search.* Paper presented at the meeting of the International Technology Alliance in Network and Information Sciences, Orlando, FL.

This paper is the first step in our research plan towards addressing the fundamental question of how software agents can best aid distributed human teams performing time stressed critical tasks in uncertain and dynamic environments. Based on prior work, we hypothesize that to improve the performance of human teams, agents must do some combination of the following: (1) reduce the cost of the humans' information processing; (2) decrease uncertainty in the task; (3) improve coordination between team members; (4) directly assist in task completion. In order to (a) establish an experimental baseline of the performance of human-only teams for some particular task domain, and (b) best understand where agents can provide best utility in supporting human teamwork, we designed scenarios and performed experiments with human teams performing a time-stressed, collaborative search task in a multi-player gaming environment. The collaborative search task recreates some of the challenges faced by human teams during search and rescue operations, such as the one described in the Holistan scenario. In our experiments, we analyze (1) verbal communication between team members and (2) the effects of presenting or omitting task progress information. By ascertaining the information processing and coordination requirements of this team task, we expect to identify "insertion points" for agent assistance to human teams. Agent assistance will be particularly critical to military teams as their operations become more agile and situation specific. As unfamiliar forces are brought together for different coalition missions, agent support of teamwork becomes crucial.

Whidbee, A. (2007, Summer). Mobile command centers put C4 & IT on the target. *The Coast Guard Journal of Safety & Security at Sea: Proceedings of the Marine Safety & Security Council.* Retrieved from http://www.uscg.mil/hq/cg5/cg534/On%20Scene/OSsummer2007.pdf.

Coast Guard SAR (search and rescue) response involves multi-mission stations, cutters, aircraft and boats linked by communications networks. As a result of expanded mission requirements, in 2002 the Coast Guard decided a system was needed which would fill the capability gaps of the current mobile communications response assets. This system is currently in production and is called the Mobile Communications Center (MCC) project. The MCC is a set of mobile and portable assets designed to provide the Coast Guard with on-scene Command, Control, Communications, Computers, and Information Technology (C4&IT) support during contingency, continuity and surge operations. The MCC was developed using the system of systems design concept to support an array of duties while maintaining interoperability with Coast Guard and Other Government Agency (OGA) partners. Under this system of systems umbrella, each asset can be deployed independently to provide mission specific capabilities, or as a complete MCC system package to provide a complete C4&IT presence. Transportable C4&IT resources are vital to the success of the response oriented Coast Guard missions. The MCC system currently meets this need with four main assets: the Enhanced Mobile Incident Command Post (eMICP), Mobile Communications Vehicle (MCV), Portable Computer Store (PCS), and Portable Secret Internet Protocol Router Network (SIPRNet - pronounced "sipper net" (PS)).

4 SUMMARY REVIEW OF TWO RESOURCE ALLOCATION/BASING MODEL PAPERS

Upon review by the Technical Authority, two methods were chosen for more detailed analyses. As previously stated in section 3 these are more detailed summaries of the two papers, offered without bias and the author does not take credit for any of the original material. The two papers selected are from the Resource Allocation/Basing Models category and include:

Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology.

Azofra, M., Perez-Labajos, C. A., Blanco, B., Achutegui, J. J. (2007). Optimum placement of sea rescue resources. *Safety Science, 45,* 941-951.

4.1 Paper 1 Reviewed

Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology. *European Journal of Operational Research, 196,* 1086-1096.

ABSTRACT: We study the problem of suitably locating U.S. Coast Guard air stations to respond to emergency distress calls. Our goal is to identify robust locations in the presence of uncertainty in distress call locations. Our analysis differs from the literature primarily in the way we model this uncertainty. In our optimization and simulation based methodology, we develop a statistical model and demonstrate our procedure using a real data set of distress calls. In addition to guiding strategic decisions of placement of various stations, our methodology is also able to provide guidance on how the resources should be allocated across stations.

The United States Coast Guard provides search and rescue capabilities throughout the States. Thousands of calls are received annually and in order to respond quickly to these emergencies, bases must be strategically located so that searches and subsequent rescues are completed quickly. Afshartous, Guan, and Mehrotra (2009) developed a methodology to analyze if the current and future locations of bases are adequately located to ensure the shortest response times. The U. S. Coast Guard did this in response to acknowledgement that this issue, based on where distress calls originate, has not been fully investigated. The resulting model is a spatial statistics model that also provides a simulation and optimization methodology that allows for determining the best location for search and rescue bases based on call locations that vary over time.

Although there are a number of models (e.g., p-median problem, p-center problem and uncapacitated facility location problem, etc.) for determining the optimal location of facilities that service the public, none of these models account for uncertainty in call locations. For example, the p-center problem determines the location of facilities based

on minimizing the maximum distance any person would need to travel to that facility. The p-median problem uses a weighted sum of distances of all of the distress calls to the closest facility. Finally, the uncapacitated facility location problem ensures that as many clients as possible are located within a pre-defined distance of a facility (Afshartous et al. 2009). These models are generally used in emergency management for determining the location of hospitals, fire stations and ambulance bases and are not sufficient for determining locations of search and rescue bases. Afshartous et al. (2009) developed the following statistical model that considers varying call locations for helping to determine optimal locations of search and rescue bases.

Prior to running any simulations to determine the ideal location for search and rescue bases, Afshartous et al. (2009) used the year 2000 U. S. Coast Guard actual call generation data to develop their statistical model. The authors defined the area of interest as an area running east to west from -59 to -87.5 degrees longitude and south-north from 10 to 34.5 degrees latitude. This area covered the coastline from Southern Alabama along Miami and north to South Carolina. It also extended south to cover Cuba, the Dominican Republic and Puerto Rico. The Coast Guard District 7 located in Miami Florida services this area.

The first step in developing the model was to assume that distress calls followed an inhomogeneous (also known as non-homogenous) Poisson process with an unknown intensity function. In a homogeneous Poisson process, the occurrences or rates of events are distributed uniformly on any interval in time. However, distress calls to the U. S. Coast Guard are not uniformly distributed on any interval in time so the inhomogeneous Poisson process was employed. The inhomogeneous Poisson process assumes that occurrences or rate parameters change over time. The intensity function in the Afshartous et al. (2009) model was the likelihood for distress calls to occur at a given location. It was further assumed that the most important factor in determining how the calls were distributed over space was traffic intensity of boats and ships. That is, the location of the boats determines where the distress calls will originate.

To estimate the intensity function, Afshartous et al. (2009) used the number of distress calls divided by the corresponding region. They further determined that most of the corresponding regions should not be circular but rather elliptical because a circular region will not account for any directional features in call distributions. When examining the actual call data, the authors noted that there was a tendency for calls to be clustered along the coastline. The intensity or likelihood for a call to occur at a given location changed significantly at greater distances from the coastline. Further, the pattern of calls paralleled the coastline further supporting an elliptical region.

Once the intensity function was estimated, Afhsartous et al. (2009) established a method of simulating distress calls. Generally when the inhomogeneous Poisson method is used, the following steps are followed:

1. A homogeneous Poisson process “with intensity equal to the largest value of the estimated intensities across the region is generated” (Afshatrous, 2009, p. 1090).

2. The second step in this process retains each simulated point from the first step with “probability equal to the ratio of the estimated intensity at the simulated point to the largest estimated intensity in the region” (Afshatrous, p. 1090).

3. The way in which the maximum intensity is derived is to lay a fine grid over the area of interest and the estimated largest intensity is equal to the calculated maximum of the estimated intensity function values at each grid node.

Afshartous et al. found that due to the extreme magnitude of the global estimate of the maximum intensity, this method produced too many calls. To remediate this problem, the authors divided the study region into sub-blocks and performed step one of the aforementioned procedure. The outcome was fewer results were simulated in low intensity sub-blocks, making this procedure computationally satisfactory.

4.1.1 Simulation Application

Upon establishing the method for simulating calls, the simulations were run to examine the station location problem for the U. S. Coast Guard District 7. The four existing stations were included in the simulations as well as eleven potential future stations chosen by the U. S. Coast District 7. All fifteen locations were included in the two integer problems. A list of these stations can be found in Table 4-1 and the corresponding acronym (e.g., S1, S2, etc.) are used in the tables displaying results for the fixed- and free-4 problems.

Table 4-1: List of Existing and Potential Future Stations

Station Name	Existing Station
Miami (S1)	Yes
Clearwater (S2)	Yes
Savannah (S3)	Yes
Borinquen (S4)	Yes
Key West (S5)	No
Homestead (S6)	No
Delray Beach (S7)	No
Ft. Pierce (S8)	No
Melbourne (S9)	No
St. Augustine (S10)	No
Fernandina Beach (S11)	No
Charleston (S12)	No
Naples (S13)	No

Station Name	Existing Station
Venice (S14)	No
Apalachicola (S15)	No

The first integer problem was a fixed-4 problem and the second was a free-4 problem. The results of fixed-4 would show a subset of stations with ten stations in total that would minimize travel distance to the distress calls with the four existing stations included in the solution. In the free-4 problem, any of the existing or future stations that minimized travel time can be chosen. A total of ten stations will be chosen and the existing stations need not be part of the solution. The goal of the simulations and solving the integer problems was to answer the following questions:

1. Are the current stations located appropriately?

2. If the current stations could be closed and new stations opened, where should stations be located?

3. What is the potential value of additional stations?

4. Are the answers to the above questions relatively stable as the distress call distribution is varied?

5. Do the distress calls exhibit a significant seasonal pattern indicating that resources should be deployed accordingly?

6. Do we obtain similar results by analyzing a smaller sample of data? (Afshatrous et al., 2009, p. 1092)

These questions were examined using the original and simulated data to investigate the robustness of the solution.

The fixed- and free-4 problems were first solved using the original data and the results can be found in **Table 4-2** and **Table 4-3** In the fixed-4 problem, the existing four stations were part of the solution for n = 4,…..,10 stations. The average total distance travelled per call when the four existing stations were chosen is 199 kilometres. When a fifth (future) station in Key West was added, the travel distance decreased by 18 kilometres (reduction of 8.9%). This reduction could potentially be the difference between life and death for someone in distress. As each additional station was added, the travel distance per call decreased by approximately 10 kilometres. If the U. S. Coast Guard were only able to add one new station, the Key West station would provide the largest reduction in travel time (Afshartous et al., 2009).

Table 4-2: Results for Fixed-4 Problem Using Existing Data
(Table 2 Original year 2000 data solutions, Afshartous et al., 2009)

Pick	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	Cost/call (km)
4	x	x	x	x												199
5	x	x	x	x	x											181
6	x	x	x	x	x										x	170
7	x	x	x	x	x							x			x	160
8	x	x	x	x	x				x			x			x	150
9	x	x	x	x	x			x		x		x			x	144
10	x	x	x	x	x			x		x		x		x	x	140

In the free-4 problem for n = 4…..,10, three of the existing stations appear to be viable locations whereas the fourth existing station (Miami station) does not appear in the solution until six new stations have been added (n = 10). It may not be that the Miami station is poorly located but rather future stations may be better options for reducing the travel time.

Table 4-3: Results for Free-4 Problem Using Existing Data
(Table 3 Original year 2000 data solutions – Free-4 problem, Afshartous et al., 2009)

Pick	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	Cost/call (km)
4		x	x	x								x				199
5		x	x	x	x							x				181
6		x	x	x	x					x		x				170
7		x	x	x	x					x		x			x	160
8		x	x	x	x				x		x	x			x	150
9		x	x	x	x				x		x	x		x	x	144
10	x	x	x	x	x			x		x		x		x	x	140

In order to investigate the robustness of the above solutions, the simulation optimization methodology was employed. The year 2000 actual data was used to estimate the likelihood for a distress call to occur at a given location and then 100 sets of simulated calls were created. The same two fixed integer problems were assessed and compared to the original data results. The results for the free-4 problem using simulated call data were almost identical to those derived from the original data with one exception. In the original data results, every time a new station was added the Key West station was included in the solution. However in the simulation when six stations were picked (adding two new stations to the existing four), the Key West station was only included in the solution in 19 of the 100 simulations and the Apalachicola station was favoured over the Key West station. Upon closer review, the Apalachicola station location would reduce travel distance by one kilometer relative to the Key West station. This difference is insignificant and it appears that the original solutions are robust across simulations.

Some of the fixed-4 problem solutions produced by the simulation were significantly different than those produced by the original data and these results can be found in **Table 4-4**. For example, the pick-7 and pick-10 simulation solutions were different from those in the original data. In all cases where the results were different, the solutions provided by the simulations reduced the travel distance. However, many of these reductions were small (e.g., 2-3 kilometers) and the Coast Guard would need to decide if the decreases in travel distance would allow for quicker response times to distress calls.

Table 4-4 Results for Fixed-4 Problem Using the Simulation-Optimization Method
(Table 5 Simulation results for the Fixed-4 problem: $Frequency_0$: Frequency of the solution for the actual data being an optimal solution in the simulated data, Afshartous et al., 2009)

Pick	$Frequency_o$	$Frequency_s$	$Solution_s$	$Number_s$
4	100			1
5	100			1
6	19	58	S1-S5, S9	4
7	10	40	S2-S5, S9, S12	5
8	86			2
9	55			5
10	22	51	S1-S5, S8, S10,S12, S13, S15	8

$Frequency_o$ is the frequency of the solution for the actual data being an optimal solution in the simulated data. $Frequency_s$ is frequency of the most frequent optimal solution for the simulated data, if different from the original data solution. $Solution_s$ is identity of the most frequent optimal solution for the simulated data, if different from the solution to the actual data. $Number_s$ Number of solutions across the simulations Afshartous et al. 2009, p. 1093)

Afshartous et al. (2009) also looked at seasonality and whether this variable would change the results derived from the previous simulations. The data were divided into two subsets covering the April – August (N = 698) and September - March (N = 928) timeframes. This analysis was done because there are more distress calls during the September – March timeframe due to hurricanes. Results showed that seasonality does create more variability in the locations of calls for both seasons and also an increase in travel distance of 12 kilometers for the September – March subset. These results would need to be further assessed by the Coast Guard to see if during hurricane season, resource allocation may need to be altered to ensure similar responsiveness.

In sum, the simulation-optimization methodology developed by Afshartous et al. (2009) is appropriate for determining the locations of Coast Guard stations. By adding call location variability, this uncertainty can be built into the model making it more realistic. Further, the solutions produced by the methodology indicate that the current location of the four existing stations for the U. S. Coast Guard District 7 are well-located with respect to travel distances to distress call locations. The results also show where new stations should ideally be located to further minimize travel distances.

4.2 Paper 2 Reviewed

Azofra., M., Pereze-Labajos, C. A., Blanco, B., & Achutegui, J. J. (2007). Optimum placement of sea rescue resources. *Safety Science, 45,* 941-951.

ABSTRACT: In countries with autonomous regional governments, the positioning of the national sea rescue resources is often a permanent source of friction between the national and regional authorities. This friction usually resurges after any heavily publicised accident. However, the process of planning sea rescue resources and their distribution in the various locations should be carried out according to scientific criteria. The aim of the present work is to build a tool which allows sea rescue resources to be assigned objectively. To this end, we formalise a general methodology based on gravitational models which allows us to define individual and zonal distribution models. Also, a practical application of the zonal model is performed, assigning 'sea rescue boats' to a segment of the coast where there are three ports.

Positioning of search and rescue bases and assigning the finite resources available to those bases is technically challenging. Many variables must be considered when determining the best location for sea rescue resources. Some of these include number and severity of accidents, types of vessels involved in accidents, locations of accidents, the search and rescue resources available for posting to bases, cost of resources and bases, etc. Additionally, political issues may also impact where resources are allocated (Azofra, Perez-Labajos, Blanco, & Achutegui, 2007). Unfortunately, political agendas do not always lead to ideal decisions regarding optimal resource location. In order to objectively determine the best location for search and rescue resources, Azofra-Colina & Achutegui Rodriguez, 2004 and Azofra et al. 2007 have proposed two gravity models that can be used for placement of sea rescue resources.

The objective of the Azofra et al. (2007) work was to develop an objective methodology for assigning or reassigning sea rescue resources such as aircraft or ships. To accomplish this, they describe two potential models: the individual and the zonal distribution models and both allow for optimal assignment of sea rescue resources. Both models consider a variety of complex variables that contribute to accidents at sea and take into account that accidents occur in a sometimes hostile and constantly changing environment. Finally, both models use historical accident data to help determine resource allocation. The factors that are included in both distribution models are characteristics of the accident, types of accidents and their severity, distribution of resources, placement of resources assigning indicators of suitability to locations and cost-effectiveness (Azofra-Colina & Achutegui Rodriguez, 2004; Azofra et al., 2007). Each factor and how some are derived for use in the model is described below.

1. **Characteristics of the accident, the vessel and the damage produced**. These include place and type of accident, consequences for the craft, number of injured persons, deaths or disappearances, number of persons on board, type of craft, age,

tonnage, time of day, month of year to calibrate the temperature of the water, and state of the weather and the sea.

2. **Classification of the accidents and establishment of a scale of severity**. In order to create a scale of severity for each accident, information about each accident must be obtained from government search and rescue data bases. These accidents are then classified as slight, moderate, serious or very serious. A slight accident results in no serious injury to crew or vessel and no external variables (wind, waves, weather, etc.) impact rescue. A moderate accident results in a greater risk of injury to the crew and more damage to the vessel and no external variables impacting rescue. Serious accidents could involve deaths, disappearances, injuries and significant damage to the vessel but no external variables impacting rescue. Very serious accidents include deaths, injuries, missing people and the external variables of weather, wind and waves seriously impact rescue. The accidents are assigned a hierarchical number (5, 3, 2, and1 point) respectively for most serious through to moderate efforts and these become the weightings for each accident (Azofra-Colina & Achutegui-Rodriguez, 2004). In the zonal model, all accidents are grouped into one category called a superaccident. The superaccident location value for each zone is derived by calculating an average latitude and longitude for all accidents within the zone. For example, adding up the longitudes of all of the accidents within a given zone and dividing that sum by the total number of accidents calculates the average longitude. The same process is used for calculating average latitude. These two averages will be the superaccident location for that zone and will be the distance to the potential bases where a resource will be assigned.

3. **Distribution of resources such as helicopter, tug-boats and rescue boats with a definition of their radius of action (i.e., maximum travel range of resource).** In order to determine which resource should go out during a search and rescue operation, the following information should be used.

    a. The characteristics of the accident, vessel and resulting damage.

    b. Functionality, operability and limitations of the resource. For example, a rescue helicopter can carry up to 25 people, is very fast and can be used for a variety of operations including rescuing people and tracking and/or pursuing suspicious vessels. One limitation is helicopters cannot fly in severe weather conditions. All of these variables need to be considered in the models.

4. **Placement of resources assigning indicators of suitability to locations.** For any search and rescue port, indicators of suitability include how accessible and operable the ports are during storms, fuelling supplies and capabilities, capacity for making repairs, infrastructure of the port, and nearby medical facilities that are accessible 24 hours a day and are sufficiently equipped to deal with trauma patients. The adequacy values range from 0 – 1 with 1 being an optimal port for a given resource, .8 a good location and so forth.

5. **Cost-effectiveness** Although a specific port may be the ideal location for a resource, the cost to support that resource may be prohibitive and the resource may need to be stationed at the next best location.

In the individual distribution model, a coefficient of the rescue resource situated at a specific location is calculated and this allows for an objective measure of where each resource should be located among a number of possible alternatives. The coefficient is expressed as:

$$IA(Rr, Pp) = SP_p, R_r \sum_{i=1}^{i=n} \left(\frac{w_i}{d_{ip}}\right) \forall i \in Radius\ of\ action\ of R$$

where $IA(Rr, Pp)$ is the individual assignment coefficient for the resource (Rr) at a specific location (Pp). The variables that are considered in the model are the suitability factor ($[SP]_{p,R_r}$) of the location for the resource, the number of accidents that have occurred within the radius of action of the resource in question and the derived weightings (w_i), the distance between accident and base locations ($d_i(i,p)$), and the radius action of the resource. For a single resource there will be a number of possible locations where the resource could be assigned. The resource should be assigned to the placement that yields the highest coefficient (Azofra-Colina & Achutegui-Rodriguez, 2004; Equation(1) p. 944, Azofra et al., 2007).

Although the individual distribution model is appropriate for assigning resources to suitable base locations, one limitation of the model is that if an accident occurs at the location where the rescue resources are located, the distance to the accident will be zero resulting in an infinite coefficient. In order to significantly reduce this limitation, the zonal distribution model was developed. This model reduces the possibility of an infinite coefficient in that the only time that the coefficient will be zero is if all the accidents within the zone occurred at the base location. This model is different from the individual distribution model in that individual accidents are not used but rather, zones where accidents occur are defined and incorporated into the model. The size of each zone is small enough that the resource can reach any point within the zone. Also, the superaccident is used in this model.

Once the superaccident location within each zone is identified, the “superaccident” within the radius of action of the resource (Rr) located at a specific location (Pp), and the same severity coefficient (W_i) used in the individual distribution model will be used taking into account the coefficient now representative of the zone (W_z) and not individual accidents (w_i). Using the above information, the zonal distribution model coefficient is:

$$ZA(Rr, Pp) = SP_p, R_r \sum_{z=1}^{z=n} \left(\frac{W_z}{d_{zPp}}\right) \forall z \in Radius\ of\ action\ of Rr$$

where $ZA(Rr, Pp)$ is the zonal assignment coefficient for the resource (Rr) at a specific location (Pp). The variables that are considered in the model are the suitability factor ($[SP]_{Pp,Rr}$) of the location for the resource, the derived weightings (W_{Sz}) of the superaccidents in the zone, the distance between accident and base locations $d_{Sz,Pp}$ and the radius action of the resource. Similar to the individual distribution model, the ZA coefficient will be different for each resource at different locations and the resource should be assigned to the location with the highest coefficient (Equation 5, p. 946, Azofra et al., 2007).

4.2.1 Zonal Model Example

Azofra-Colina and Achutegui-Rodriguez (2004) provide an example of how resources are assigned using the zonal distribution model and they used the 1992-1999 accident data for the Basque Country in Spain. These accidents had a total weight of 164 and an average of two. Four were very serious, 18 serious, 30 moderate and 30 slight. The area under study was divided into 17 zones approximately 10 by 10 miles each and the superaccident for each zone was calculated. There were two towboats and one helicopter that needed to be assigned to locations. The first potential assignment for the towboats had each boat going to two separate stations and the second had both towboats assigned to the same station. The helicopter was to be allocated to one station.

To determine the two best locations for the boats, the radius of action for each towboat was determined to be 25 miles and there were seven existing ports that were deemed suitable. These included Fuenterrabia, Pasajes, San Sebastian, Guetaria, Lequeitio, Bermeo, and Bilbao. Finally, weightings for the superaccident and distance from the ports to each zones' superaccident were calculated. **Table 4-5** shows seven coefficients were derived for assigning one towboat to different stations.

Table 4-5: Results for assigning One Towboat
(Extract from Table p. 54, Azofra-Colina and Achutegui-Rodriguez (2004))

Basque Country	Coefficient	Appropriacy of Port	Weight	Average Distance
Fuenterrabia	8.15	0.75	164	30.3
Pasajes	27.37	0.82	164	25.7
San Sebastian	14.64	0.82	164	24.9
Guetaria	10.72	0.75	164	22.1
Lequeitio	14.29	0.75	164	20.2
Bermeo	11.56	0.82	164	22.5
Bilbao	29.11	0.93	164	31.1

The Bilbao and Pasajes stations were deemed to be the most appropriate location for the allocation of one tugboat. Upon closer review of the results, the coefficient, average distance from the two ports to the zones' superaccident, and the suitability of port value all indicated that the two ports identified by the model were the appropriate choices. Subsequent analyses for independently posting the two towboats and one helicopter to one port can be seen in **Table 4-6 Table 4-7**.For placement of the helicopter, there are only three possible locations.

Table 4-6: Results for assigning Two Towboats
(Extract from Table p. 55, Azofra-Colina and Achutegui-Rodriguez (2004))

Basque Country	Coefficient	Appropriacy of Port	Average Distance
Fuenterrabia	10.01	0.75	
Pasajes	27.24	0.82	13.4
San Sebastian	14.61	0.82	12.9
Guetaria	11.15	0.75	13.4
Lequeitio	15.44	0.75	
Bermeo	14.52	0.82	18.8
Bilbao	33.15	0.92	13.1

No average distance values were provided by the authors for Fuenterrabia and Lequeitio. It is unclear why these values were omitted.

Table 4-7: Results for assigning One Helicopter
(Extract from Table p. 57, Azofra-Colina and Achutegui-Rodriguez (2004))

Airport	Weighting	Coefficient	Distance (km)
Fuenterrabia	247	8.20	104.9
Pasajes	334	9.1	74.8
San Sebastian	356	9.24	65.1

Upon review of the Azofra-Colina and Achutegui-Rodriguez (2004) and Azofra et al. (2007) model, a number of shortcomings have been identified. In both papers, the authors state that characteristics of the accident, the vessel and the damage produced are factors in the model but it is unclear how these factors are applied in the model. Second, characteristics of the rescue resources and accident characteristics are mixed together in the same factor. They should separate factors in the model. Third, the

authors include cost-effectiveness in the model but it is unclear from the formula if this factor is actually included in the model.

Finally, the authors' justification for creating a zonal model appears to be weak. The infinite coefficient problem could be solved by simply adding a small value to the denominator. Additionally, a better reason for creating a zonal model would be to reduce data processing. For example, instead of analyzing thousands of accidents in a small area, create zones with singular representative "superaccident" characteristics.

Azofra et al. (2007) Azofra-Colina and Achutegui-Rodrigues (2004) have introduced the individual and zonal distribution models for objectively assessing the best location for placement of sea rescue resources. The two models include a variety of variables such as accident severity and location, radius of action of the resource and suitability factors to derive an assignment coefficient. The individual distribution model uses the weightings of individual accidents whereas the zonal distribution model categorizes accidents that have occurred within a pre-determined zone. Although both models guide the placement of resources, the zonal distribution model does not produce an infinite coefficient and this makes it a more robust model.

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4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

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5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
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9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
DRDC CORA ARP 13rj01	DRDC CORA SA Task 132

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
5298-002 Version 04	DRDC CORA CR 2013-014

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

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This document is a deliverable associated with the project entitled "National Search and Rescue Literature Review". The purpose of this project was to conduct a literature review and develop an annotated bibliography of existing analytical techniques, models and methods that have been applied to the delivery of search and rescue. This report was completed by CAE Professional Services (Canada) Inc. (CAE PS) under Task #132 for contract #W7714-083663/001/SV to Defence Research & Development Canada (DRDC) Centre for Operational Research and Analysis (CORA).

This document contains an annotated bibliography and review of Canadian and foreign search and rescue studies related to resource allocation/basing models, response posture, strategic policy, tactics and procedures and search techniques associated with aeronautical, maritime and humanitarian search and rescue. The first objective of the current work was to conduct a literature search and create an annotated bibliography outlining the papers resulting from the search. The second objective was to summarize two papers chosen by the Technical Authority. The two papers chosen were from the resource allocation/basing models category. The papers summarized were:

Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology. European Journal of Operational Research, 196, 1086-1096 and Azofra., M., Pereze-Labajos, C. A., Blanco, B., & Achutegui, J. J. (2007). Optimum placement of sea rescue resources. Safety Science, 45, 941-951.

Ce document est issu du projet d'analyse de documents sur les opérations nationales de recherche et de sauvetage. Ce projet visait à faire une analyse documentaire et à constituer une bibliographie annotée des techniques, des modèles et des méthodes d'analyse en vigueur qui ont déjà été appliqués à la prestation des services de recherche et de sauvetage. Ce rapport a été produit par CAE Professional Services (Canada) Inc. (CAE PS) dans le cadre de la tâche no 132 pour le contrat no 7714-083663/001/SV confié au Centre d'analyse et de recherche opérationnelle (CARO) de Recherche et développement pour la défense Canada (RDDC).

Ce document contient une bibliographie annotée et une analyse des études canadiennes et étrangères sur les services de recherche et de sauvetage sous l'angle des modèles d'allocation et de mise en place des ressources, de la posture de réponse, de la politique stratégique, des tactiques et des procédures et des techniques de recherche associés aux opérations de recherche et de sauvetage aéronautiques, maritimes et humanitaires. Le premier objectif des travaux actuels était d'effectuer une analyse documentaire et de créer une bibliographie annotée énumérant les documents mis au jour par cette recherche. Le second objectif était de résumer deux articles choisis par l'autorité technique. Les deux articles choisis traitent des modèles d'allocation et de mise en place. Les documents résumés sont :

Afshartous, D., Guan, Y., Mehrotra, A. (2009). U.S. Coast Guard air station location with respect to distress calls: A spatial statistics and optimization based methodology. European Journal of Operational Research, 196, 1086 à 1096 et Azofra., M., Pereze-Labajos, C. A., Blanco, B., & Achutegui, J. J. (2007). Optimum placement of sea rescue resources. Safety Science, 45, 941 à 951.

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