Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

SEARCH AND RESCUE MANAGEMENT: MODELLING AND DEVELOPMENT OF HEURISTIC STRATEGIES WITHIN A SIMULATION ENVIRONMENT

A THESIS PRESENTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY IN
OPERATIONS RESEARCH
AT MASSEY UNIVERSITY, PALMERSTON NORTH,
NEW ZEALAND.

Fiona Helen Wharton

2000

Where such references to “man”, “he”, or “his” appear in the body of this thesis, they have been used only to avoid the awkwardness of “man/woman”, “she/he”, or “his/her” constructions, and as such should be understood in their generic context.

Abstract

The search for a lost person on land has been the subject of relatively little research to date in comparison to other search problems. This thesis addresses this imbalance by examining the search for a stationary object that does not attempt to avoid detection. The problem is defined as a synthesis of the coverage, routing, and allocation problems that exist in the literature, and its complexity and unique aspects are discussed.

A physical model of the search terrain is developed using a Triangulated Irregular Network (TIN). This model incorporates the vegetation and natural features of the terrain, and is extended to model access paths and traversal speeds between any two points. A visibility model is developed over the TIN in order to define a detection model for both a human subject and any clues placed by him. Correction factors are used to model visibility and traversal speeds under different search environments.

Methods to define search regions as components of the elements of the TIN are described. Heuristic resource allocation methods are then developed for both the reconnaissance and general phases of a search operation. These methods allocate search tasks to resources individually or in parallel, and in real-time. Dynamic heuristic search strategies to respond to changing search conditions and the discovery of new information are then developed.

A Discrete Event Simulation (DES) model of a Search and Rescue (SAR) operation is developed. This model incorporates: siting a search base; search resource deployment and searching; clue and subject detection; communication between resources and search management; flooding and resource deployment under adverse weather conditions; and responsiveness of the subject over time.

The simulation model is used to perform some preliminary computational experiments on a restricted set of resource allocation methods and search strategies. Initial trends indicated from these experiments are: the general superiority of methods which do not

restrict the set of regions to be allocated for searching to an initial primary search area; the dominance of a night searching strategy; the dominance of using a sound detection method when a subject is responsive; and the benefits of applying diversifying search strategies.

Acknowledgements

The completion of this thesis has been achieved with the input, resources and encouragement of many people.

- *Tony* - my husband and best friend, for his unending encouragement, love and understanding, and for his patient data entry and editing.

- *My family* - for their years of support and continued attempts to understand what this "OR thing" is all about, and for their practical help with proofreading, editing and diagram creation.

- *John Giffin* - my chief supervisor, for his perseverance and technical critique.

- *Mark Johnston* - for his patience, time and practical expertise in sourcing, trialling and installing software for me, and showing me what to do with it. Particular thanks are due for creating the majority of the diagrams.

- *Fana To'omaga* - my brilliant typist who deciphered my scrawlings and dictation to put many of these words on paper; and to *Workbridge* for providing her funding.

- *Ross Gordon, Emergency Management Ltd.* - for his realist's point of view, total enthusiasm for the research, and the contacts he enabled with overseas SAR experts.

- *New Zealand Police Search and Rescue personnel* - particularly Inspector John Meads, NZ SAR Coordinator, for allowing me access to Police resources and providing the opportunity to participate in the national SAR training course.

- *Richard Rayner* - for initially showing me the ropes with C, LaTeX and UNIX.

- *My good friends* - for keeping me sane. Special thanks to *Kathryn Redhead, Shalome Campbell, Sharlene Pilkinton, Bernadette Murray and Nic Gidden*, for their help with typing and proofreading in the final weeks.

Glossary of Terms

The following specific terms are referenced throughout this thesis:

Binary Search A search method used to eliminate areas that the subject has not passed through.

Coverage (C) The ratio of search effort to the size of the search area.

Critical Separation The spacing of ground search resources at a distance equal to two times the visibility measure of that terrain.

Double Strip Search A form of grid searching where a region is searched twice from two different angles.

Hot Spots Likely places for physical clues to be detected.

Lateral Range (x) The perpendicular distance between a search resource and the search object at the point on the resource's path which is closest to the object.

Lateral Range Curve A curve depicting the cumulative probability of detection for a given search resource as a function of x, with one pass.

Mattson Consensus Technique A technique which guides search management to a consensus decision in defining POA values for search regions.

PDEN The Probability of Density. A measure used to rank search regions calculated on the POA value divided by the size of the search region.

Perimeter Cut A search technique where resources search along the boundaries of the search area for clues.

PLS The Point Last Seen represents the last known location of a search object.

POA The Probability Of Area.[1] The probability that the search object is located within a given search region.

POD The Probability Of Detection. The conditional probability that if the search object is in the search region it will be detected by the search resource. We use the word detection in the context of detection with recognition.

POD$_{\mathbf{cum}}$ The cumulative probability of detection over a number of successive searches of a search region.

POS The Probability Of Success of a search as measured by the detection of the search object and calculated as POA $\times$ POD.

POS$_{\mathbf{cum}}$ The cumulative probability of success over the search operation.

Priority Search Area (G_P) The subset of the search region graph which is identified as having the highest likelihood of containing the subject and on which searching is concentrated. This area is of a size that is able to be searched by the search effort on hand within one search period.

Probability Map A map of the search area depicting POA values in each subarea.

PSR The Probable Success Rate. A measure of the rate of POS increase to be expected when searching a region.

Repeated Expansion A search technique which begins by searching a small area centred on a specific reference point, and then successively re-searching this area in incremental expansions in an outwards direction.

Risk Map A visual map identifying hazards over a given region.

ROC Relevance Of a Clue to the search operation.

ROW The Rest Of the World. A pseudo-region representing any area outside of the defined search area.

Search Priority A myopic planning tool which ranks search regions for searching based on their contribution to POS and the time taken to achieve this.

Search Effort (Z) The area which can be effectively swept by a given search resource given its sweep width and the distance travelled by the resource.

[1] Also referred to in the literature as the Probability of Containment.

Search Object The object of a search. This includes human subjects as well as organic and inorganic clues.

Search Path The path of edges and/or triangular regions that a search resource is assigned.

Search Region A well-defined region assigned to a search resource for searching.

Search Region Graph (G) The 2-D graph derived from the TIN.

Search Resource A resource assigned to the search area to search for the search object. Such resources include human searchers, aircraft, dogs, and mechanical or electronic devices. Also referred to as a sensor, we refer particularly to a human searcher when using the term search resource within the body of the thesis.

Sector Stripping A method which removes search resources from one search region in favour of searching an alternative region in order to increase POS.

Sector Laddering A method which ranks search regions in a ladder formation with the top-most region having highest priority and regions being placed at the bottom of the ladder upon search completion. Regions whose priority is adjusted throughout the operation are moved to appropriate positions on the ladder.

Sound Sweep A search technique where search resources moving in a grid formation aim to detect a responsive subject by calling out at regular time intervals and listening for a response.

Sweep Width (W) The area under the lateral range curve - "a measure of the amount of 'detecting' being done" [150, page 4-4]. The sweep width differs for different search objects, search resources, and search conditions.

TIN Triangulated Irregular Network. A digital terrain model which geometrically partitions the terrain into triangles by a triangulation generated over a representative set of data points.

Track Traps Ground cleared for the purpose of observing if fresh tracks are laid.

Trail-Based POA A method of assigning POA values to a search area based on the possible behaviour of a subject initially known to have followed a marked path. POA values are estimated from the findings of a team who follow this path identifying and ranking decision points where the subject may have left the path.

The following variable definitions are utilized in the algorithm descriptions:

$start_k$ = the starting position (vertex) of resource k

$resources$ = number of search resources

$path_{k,j}$ = vertex at position j on the nodepath of resource k

num_k = number of vertices in the path of resource k

$time_k$ = amount of time required to complete the path of resource k

$path\_limit$ = the duration limit of any search path assignment

$path_{I,j}$ = vertex at position j in the intended path of the subject

num_I = number of vertices in the intended path of the subject

$time_I$ = amount of time needed to complete the intended path of the subject

$c_{i,j}$ = time cost of traversing edge (i,j)

$stpath_{i,j}$ = shortest path from vertex i to vertex j

$D_{i,j}$ = time length of shortest path from vertex i to vertex j

PLS = point which the subject was last seen at

$POS_{i,j}$ = POS value predicted from the search of edge (i,j)

$base$ = search base

$limit_k$ = 1 if resource k is at their search hour limit, = 0 otherwise

POA_i = POA of region i

POD_i = POD level at which region i is to be searched at

$POD_{cum,i}$ = cumulative POD of region i

$area_i$ = area of region i

$nregions$ = number of regions in the search region graph

$find\_team$ = resource which detects the subject

$urgency$ = urgency level of the search

$period\_start$ = commencement time of the next search period

period_end = time at which the current search period will be completed

down_time = amount of non-searching time between consecutive search periods

weather_level = level of current weather conditions

new_weather = predicted weather level arising at *weather_clock*

flood_time = the time at which regions of the TIN susceptible to flooding will flood and become impassable

lost_region = the region of the TIN in which the subject is located

cost_change = array which monitors the fraction of the current search task completed under differing environmental conditions, for each active resource

periodct = index of search periods

recall = indicator of whether or not resources are being recalled to the search base

suspend = indicator of whether or not the operation is being suspended

Table of Contents

List of Figures

List of Tables

List of Algorithms