Tuesday 15 September 2009

SARINZ Trust
C/- SARINZ Limited
PO Box 39 067
Harewood
CHRISTCHURCH

RE: Sound/Light Line Detection Index (POD) Experiment Methodology

Dear SARINZ Trust

Please find attached the full summary report on the Sound-Light Line Detection Index (Sweep Width) Experimental Methodology project sponsored by the SARINZ Trust.

The report marks a unique stage in the development of New Zealand SAR utilising a scientific approach to quantify the effectiveness (detection rate) of a search method. The report builds on the technique developed by Ross Gordon and Tony Wells and gives their work validity for promoting in the scientific and operational SAR worlds.

The report provides a valuable operational, marketing and business opportunity both nationally and internationally for SARINZ.

The report, written by Robert Koester, provides comprehensive coverage of the methodology and process. The key sections of the report that I would like to draw your attention to are the Executive Summary, Experiment Results, Conclusion and Recommendations.

Key project metrics

Project Title:	The development of the methodology to conduct sweep width experiments for sound and light land based search methods
Project sponsor:	SARINZ Trust
Project Manager:	Tony Wells
Lead Researcher:	Robert Koester, dbS Productions
Assistant Researchers:	Ross Gordon, Tony Wells
Support Organisations:	SARINZ Ltd, Tasman Land Search and Rescue, Tasman Police

Specific Objectives:		Result
1	The design of an "international best practice" experiment	Achieved
2	The development of	
	• experiment overview and process (why)	Achieved
	• set up instructions, process and experiment guidelines (how, where etc)	Achieved
	• a list of equipment and data collection forms/templates (what)	Achieved
3	Concept testing during development	Achieved
4	A full field-test of the experiment design & development of preliminary data	Achieved

All of the specific outcomes from the proposal were achieved on time and on budget. Collation and analysis of the data took longer than expected, delaying the production of the full report. This delay was somewhat expected given the complexity of conducting a 'world first' trial and the issues such a ground breaking trial encounters. A number of these delays will be mitigated in future trials by implementing the recommendations listed in the full report.

Marketing Strategy:

The report provides a major marketing platform for the SARINZ brand. This is the first trial of its type anywhere in the world using unalerted searchers and unalerted subjects (ie: the trial was conducted as close to operational reality as possible). The data is directly applicable in an operational context, where both the searcher and subject will be unaware of each other until some form of contact is made (voice, whistle, light). To gain the maximum marketing advantage for SARINZ, exposure of the trials and data is needed on the international stage. This will bring prestige and firmly establish the SARINZ brand as a centre of excellence in the international SAR world.

It is my recommendation that SARINZ Trust, in conjunction with SARINZ Ltd, present these, and subsequent findings, at the following key global SAR conferences in 2010.

May 2010	Washington State SAR Conference, Skamania County, Washington. USA
May 2010	NASAR Conference, USA (location yet to be confirmed)
Sept 2010	Mountain Rescue England and Wales (MREW) Conference, United Kingdom
Oct 2010	SARscene Conference, Regina, Saskatchewan, Canada
Oct 2010	ICESAR Conference, Iceland
Nov 2010	LandSAR Conference, Hokitika

Future Recommendations:

The full report attached contains a number of recommendations, and completion of these recommendations will:

1. Enhance the operational usefulness of the data,
2. Ensure that the investment thus far is maximized.

The proof-of-concept trial produced results that require confirmation through further trials. Once this data is confirmed it will change SARINZ Ltd teaching practice and by default change operational practice. These changes will occur at both a field and management level, and will have an impact on SAR teaching globally. At this stage, it would be unwise to change teaching practice based on the results of one trial.

The trial did provide scientific facts and context around what has previously been anecdotally based. Whilst a one off trial provided the preliminary baseline findings and certainly provided proof-of-concept testing, a number of trials in differing terrains are required to build a base of data that provides operational usefulness.

"This is the first report in the land search literature of both elements (searcher and subject) of a two-way detection problem. It also, however, represents only a pilot experiment. The true value of the experiment will only be realized with follow-on experiments conducted in different terrains and correction factors (wind, rain, hearing, etc.) determined. Once the additional work is accomplished, the research can move from a research and development phase to actually helping search planners to make practical decisions in the field".

It is my recommendation that SARINZ Trust continues to support additional trials to build on the comprehensive body of work and investment to date. Based on the costs of the initial trial it is estimated that each additional trial will cost approximately $10k. This is based on $5k for conducting the running of the trial and includes the reconnaissance, setup, travel, accommodation, printing and miscellaneous trial costs all of which would be performed by SARINZ personnel. The other $5k is required to fund the approximate 60 hours of post trial processing of the data by dbS Productions in Virginia USA..

Summary:

The testing methodology and subsequent report mark a milestone in land based search research in New Zealand and around the world. To maximize the benefit that this opportunity presents, further trials need to be conducted and the results presented on a world stage. In an ideal world all of the trials recommended in the full report would be conducted promptly, however this is an unrealistic objective due to cost, time and personnel restraints. However if two of the recommended trials could be conducted prior to August 2010 this would provide a reasonable amount of data to present at the MREW conference in September, SARscene conference in October and the LandSAR conference in November 2010.

Special thanks must go to:

- SARINZ Trust as the project sponsor, without whom the testing methodology and subsequent trial would never have occurred,
- SARINZ Limited for providing funding to cover the costs of the initial trial and the salary payments of the assistant researchers,
- Sherp Tucker, Tasman police district Assistant SAR Co-ordinator who provided the trial location, sourced the volunteers and supported the project and trial,
- Tasman Land Search and Rescue volunteers (and the one Canterbury volunteer) who volunteered their time to participants in the trial.

If you have any questions regarding the report, trial or future recommendations please feel free to contact me at any of the details below.

Kind regards

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"helping others save lives"

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Sound-Light Line
Detection Index Experimental Methodology
for
Search and Rescue

SARINZ
SEARCH AND RESCUE INSTITUTE
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For SARINZ Trust

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09.09.2009

dbS

Executive Summary

The goal of search and rescue (SAR) is to locate and assist missing persons in a timely fashion. Search theory is one tool that a search planner uses to make the often difficult choice of where to allocate resources. Most SAR incidents are resource poor, so the optimal allocation of limited resources is often the difference between life and death.

Search theory is completely dependent upon an accurate assessment of how well a search area was covered by a team. Previous studies have found searchers cannot accurately assess what they have missed or determine the probability of detection. Fortunately extensive research from the field of operations research has determined the factors needed to determine a meaningful probability of detection. Key to the formula for an objective probability of detection is the effective sweep width or detection index. The detection index takes into account the nature of the sensor (hearing and seeing ability of the searcher), the environment, and the search object (a reply from the search subject). The detection index must be determined in a manner similar to actual searches. This involves using actual searchers on a typical SAR task of sufficient length, with realistic subject response, sufficient number of detection opportunities, covering the full-spectrum of the lateral range curve; and the searchers must not be alerted to the locations of the subjects. The methodology developed for this experiment accomplished those requirements.

In order to test the methodology, two pilot experiments were carried out at Nelson Lakes along the Porika Road track. The first experiment was conducted during the day with six subjects and fourteen two-person teams conducting a sound line tactic. The detection index for a search team hearing a shout was 332 meters. The detection index for a subject hearing a whistle was 401 meters. Searchers were able to detect 99% of high-visibility clues (orange gloves) and 52% of low-visibility clues (gray gloves) on the track. The day-time experiment also had one search subject with a 70% hearing loss. The correction factor for the detection index was 0.35 for this level of hearing loss.

The night experiment was conducted at the same location, but with different search subjects placed in different locations. Search teams used a sound-light line tactic in two-person teams. The detection index for a search team hearing a shout was 306 meters. The detection index for a subject hearing a whistle was 395 meters and seeing a light 277 meters. The detection index for a subject seeing either signal was 460 meters.

The experiments clearly show it is possible to determine the detection index for both the searchers' and subject's perspective. This is the first report in the land search literature of both elements (searcher and subject) of a two-way detection problem. It also, however, represents a only a pilot experiment. The true value of the experiment will only be realized with follow-on experiments conducted in different terrains and correction factors (wind, rain, hearing, etc.) determined. Once the additional work is accomplished the research can move from a research and development phase to actually helping search planners to make practical decisions in the field. To that aim, the experiment lists several key findings and recommendations to improve the methodology and carry out additional work.

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Abbreviations and Acronyms Used

AMDR	Average Maximum Detection Range
AOR	Area of Responsibility
CPA	Closest Point of Approach
IAMSAR	International Aeronautical Maritime Search and Rescue
IDEA	Integrated Detection Experiment Assistant
NSARC	National Search and Rescue Committee
OEG	Operations Evaluation Group
POA	Probability of Area
POD	Probability of Detection
PODcum	Cumulative Probability of Detection
POS	Probability of Success
R&D	Research and Development
SAR	Search and Rescue
SRU	Search Rescue Unit
US	United States
USCG	United States Coast Guard
W	Width

Part I – Introduction and Background

1. Introduction

Searching, a common activity is the process of seeking something in a conscious, careful manner. For this reason the process is often taken for granted. Searching in a limited uncomplicated environment may be simply a matter of just looking around for the lost or missing object. In the search and rescue context the circumstances and the environment of the search are often complex. This complexity requires a high level of organization familiar to those engaged in search and rescue. Much progress has been made in the organization of the management, logistics and teams necessary for a successful operation. A considerable amount of progress has been made in resolving the question of generally where to search (Koester, 2008). Much less attention has been directed toward the description and quantification of the detection process or the optimal allocation of searching effort. The detection process is the foundation on which a successful, quantifiable search planning structure can be built. This report continues the development of a method, suitable for use in a variety of land environments, for determining the Probability of Detection (POD) based upon actual field data. These data will take into account the parameters affecting a search, including searcher, search object, and the environment of the search. The successful application of accurate POD values will improve the search planning process and lead to an improved method of tracking the Probability of Success (POS) and allocating resources and effort. As always the goal of this work is to speed the safe return of persons who are missing.

During the Second World War a formal scientific discipline called search theory was established. The original work as well as all subsequent work has shown the "*…operation of search as an organic whole having a structure of its own—more than the sum of its parts*" (Koopman, 1980). Although most would regard the mathematics of search theory as complex, it can be reduced for practical use to a few simple concepts and organizing principles. Implementing these concepts and principles in a manner appropriate to the type of search mission, operating environment and available search resources has repeatedly demonstrated its value. For the search and rescue (SAR) mission, the objective is to deploy the available resources in a fashion that achieves maximum probability of success (POS) in the minimum time.

Koopman (1980) described three basic pitfalls to avoid when studying the operation of search with a view toward improving it. These were:

- Focusing primarily on basic sensing capabilities without sufficient emphasis on how to use or deploy the available sensors to maximum effect in a search.
- Trying to provide practical search planning guidance *without first obtaining the scientific background and data* necessary to provide sound guidance.
- Inappropriate handling of the mathematics by either trying to eliminate it altogether, thus eliminating much of the reasoning essential to providing practical advice, or by going to the other extreme and elaborating it to a degree of generality not required by either the theory or the practice of searching.

This project has attempted to avoid these pitfalls. In particular, it examines only the basic concept of detection. In so doing, it opens the door to solving a fundamental issue that land SAR search planners have struggled with for many years. That issue is how to objectively and reliably estimate the probability of detecting (POD) a search object if it is in an area that is to be or has been searched.

1.1 The Report

This report records the design, conduct, and results from land detection experiments using sound and light line search tactics. The major purpose of the report is to describe the experimental methodology used. The methodology was tested by performing two pilot experiments. The results of the experiments are described. These results, while preliminary, are significant first steps to better characterizing the detection index and along with this purpose, the report describes potential future experiments needed.

1.2 Previous Sound Experiments

The only two previous experiment involving sound has been conducted. In 1992 Martin Colwell conducted field trails to determine both visual and sound Probability of Detection (POD) in British Columbia. More specifically the experiment was conducted in a Pacific West Coast coniferous forest (Marine Temperate ecoregion division). The experimental methodology involved placing dummies in a standing position. The dummies were outfitted with inexpensive, portable, battery powered AM radios. The radios were tuned to a local “talk” radio stations the volume adjusted to best match a person talking loudly or shouting. Manson (2008) reports that some of the researchers who had placed the subjects were also involved in the detection experiment. Colwell’s results are reported as the searcher’s POD based upon the spacing. While this allows creation of a lateral range curve and therefore finding the area under the curve (one method to determine an effective sweep width), this value was not calculated at the time. The actual value would be expected to be underestimated since the experiment required the searcher to also make a visual detection of the search subject in order to identify the dummies code number. Manson (unpublished) conducted research in 2008 looking at sound in the same environment as Colwell. He looked at the relationship of loudness and range using different whistles. His experiments showed that loudness does not always directly indicate a whistles range, since pitch is also an important factor. The experiment reports an attention-getting range for each source, although this was a subjective value determined by the testers. To date no experiment has attempted to determine the detection index or effective sweep width value that is required to determine an objective POD. In addition, no experiment has ever been conducted to look at the use of light in getting a subject to respond. Finally, no previous experiments have looked at the real-life issue of the signal from the team must be detected by the subject and then the response signal from the subject must be detected by the team.

1.3 Probability of Detection (POD)

Successful search planning, whether in an urban, wilderness, or marine environment requires an objective standard for providing an estimate of the probability of detection (POD). In each of these settings the variables that describe the searcher, the search object, and the search environment will differ not only in kind but also in their influence on the estimate of the POD. What is constant, however, is that POD estimates should be based on objective measures and observations rather than on intuitive and therefore highly subjective assessments by either the search planner or the searchers. POD estimates are needed for both planning searches and evaluating unsuccessful search results as a prelude to planning the next search. POD is a function of the level of effort, the size of the search area segment, where the effort was expended, and how easy or hard it is to detect the object(s) of the search. A searcher is generally a reliable source of information on the search environment experienced during the search and his/her physical condition, fatigue, level of training and experience that bear on the searcher's capabilities, etc. However, at the end of the day, the only direct detection information the searcher can reliably report is what objects, if any, they detected and approximately where and when they were detected. Searchers should be required to report only what they can observe; search planners and managers should estimate POD values based on those observations and the results of detection experiments performed as outlined in this report.

Detections are only a subset of all detection opportunities. Detection opportunities also include failures to detect the search object even when there was an opportunity to do so. Since no sensor is perfect, a scientific detection experiment must consider all detection opportunities in order to establish how "detectable" a particular type of object is by a given sensor in a given environment. The measure of "detectability" is called the ***effective search (or sweep) width*** in the scientific literature and in maritime search planning. This term is ***not*** to be confused with any of the following: search visibility, detection range, visibility distance, sweep searching, grid searching, parallel sweeps, sweep spacing, critical separation, or track spacing. All of these latter terms describe either some measurement that does ***not*** reflect detection performance or they describe some aspect of how searching is done by the searchers. Effective sweep width, on the other hand, is a basic measure of how easy or hard it will be for a searcher to detect the search object under the environmental conditions that exist at the scene of the search. The larger the number the more detectable the search object. Effective sweep width may also be called a "**detection index**," especially if that seems less confusing. For the reminder of this report the term detection index will be used.

The procedures described in this report are intended for use by SAR managers to conduct experiments to establish *detection index* values for their searchers, local operating environments, and typical search objects. It should not be confused with an attempt to provide search planning guidance or define search methods and tactics. Detection index is only one part, albeit a critical one, for planning efficient, effective searches. By establishing a set of search parameters that approximate a hypothetical search situation and then by collecting data on detection/non-detection performance for each detection opportunity, a SAR organization can develop a useful measure of search object "detectability" (effective sweep width) for planning and evaluating searches in its area of responsibility (AOR). To be precise, POD is an estimate of how likely a search of a particular well-defined area will be successful, *assuming the search object was there to be found*. That is, POD is a *conditional* probability, the condition being the assumption that the object is present in the area searched. The probability of success, POS, is the joint probability formed by the probability of the object being in the area searched (POA) and the probability of detecting the object if it was there (POD). That is, POS = POA × POD. POD depends on three things:

- The "detection index" for the combination of search object, search environment, and sensor (e.g., auditory search from the ground) present in a given search situation,
- The amount of effort expended in searching the area, and
- The size of the area where the effort was expended.

The size of the search area requires special comment when the field technique of a sound light line is being used. The tactic places a team of searchers following a linear feature. Since each member of the team follows the same course, increasing the number of team members does not increase the total track line distance. Instead, any advantages of additional team members would be derived from factors such different abilities to hear, differences in types of whistles, differences in listening orientation, differences in attention, and other subtle factors. The size of the search area, since linear in nature, should be defined by how far off the route a POD is desired. This also simplifies the inputs and computation required to determine the POD value.

Given measures of these three factors in consistent units, it is possible to establish an objective, reliable, and accurate estimate of POD.

2. Scientific Background

B.O. Koopman (1946, 1980) established the basis for a rigorous study of search theory and practice with his pioneering work for the U. S. Navy during WWII. Prior to his work there was no published scientific literature on search theory. Koopman was a member of the Navy's *Operations Evaluation Group* (OEG). An important characteristic of this group was that its members were required to spend several years in the field working directly with operations personnel. All work produced by this group had to be both scientifically sound and practical enough for operational use by Navy personnel without requiring them to have any special scientific training. It also had to show practical results. The work initially done by the OEG was instrumental in winning the Battle of the Atlantic against the German U-boats. Although this kind of application may seem far removed from searching for lost persons on land, the basic theory of search Koopman established applies to all types of searching. An essential part of Koopman's work was developing the concept of effective search (or sweep) width—an objective numeric measure of how easy or hard it is for a given sensor to detect a given object in a given operating environment. While perhaps a more intuitive term would be detection index. Whenever the basic theory has been applied, substantial improvements in search success rates and reductions in the average times and resources required to achieve success have been realized. It is Koopman's work that will form the basis for the detection index estimation technique developed in this paper. For a detailed elaboration on the development of the theory see Frost (1999a, 1999b, 1999c, & 1999d).

Although search theory was applied to military SAR operations during and after WWII, the U. S. Coast Guard provided the first comprehensive application to civil SAR in the 1950s. The methodology was incorporated into the first edition of the *National Search and Rescue Manual* in 1959 and it quickly gained acceptance by maritime SAR agencies worldwide. It 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)* published jointly by the *International Maritime Organization* and the *International Civil Aviation Organization* and recognized globally as the standard text on aeronautical and maritime SAR operations and methods.

The technique and experimental methods necessary to determine detection indexes have been adapted and modified for experiments carried out on land. Koester et al (2004) reported on five visual experiments conducted in different environments for high, medium and low-visibility search object approximating prone search subjects.

2.1 "Detectability"

One of the weaknesses of the original implementation of search theory by the U. S. Coast Guard was that the "detectability" data available until the late 1970s reflected primarily maximum detection ranges for maritime SAR objects such as life rafts. There is only a very loose relationship between maximum detection range and the measure of detectability known as the detection index. In other words, the data originally available were not a very good measure of detectability and they tended to be optimistic, producing detection index estimates, and POD values, that were larger than they should have been.

In 1978 the U.S. Coast Guard Research & Development Center began an extensive data collection project to measure the detection indexes for a wide variety of realistic SAR objects, under realistic environmental conditions using actual Coast Guard crews and Search and Rescue Units (SRUs). The experiments were conducted over a period of more than twenty years. The data collected and the lessons learned during this series of experiments formed the basis for the *National SAR Manual* and *IAMSAR Manual* sweep width tables and search planning guidance, including POD estimation. In developing the methodology for the estimation of detection indexes for land search it is possible to draw upon the experience of the maritime SAR community while acknowledging the considerable differences in search techniques and environments found on land. The common link between evaluating detectability in the maritime and land environments is that each searcher/search object interaction is resolved as either a detection, or a non-detection.

2.2 Lateral Range

The method for estimating the detection index uses the concept of a "lateral range curve". This concept, introduced by Koopman (1946), has a number of properties that recommend it for detection index estimation. Lateral range refers to the perpendicular distance an object is to the left or right of the searcher's track where the track passes the object. Thus it represents the distance from the searcher to the object at the closest point of approach (CPA). A lateral range curve is a plot of the probability of detecting the object on a single pass as a function of the object's lateral range from the searcher's track, i.e., as a function of how closely the searcher approaches the object. **Figure 1** shows a hypothetical relationship between POD on a single pass and an arbitrary scale of distances to the left (negative) and right (positive) of the searcher's track.

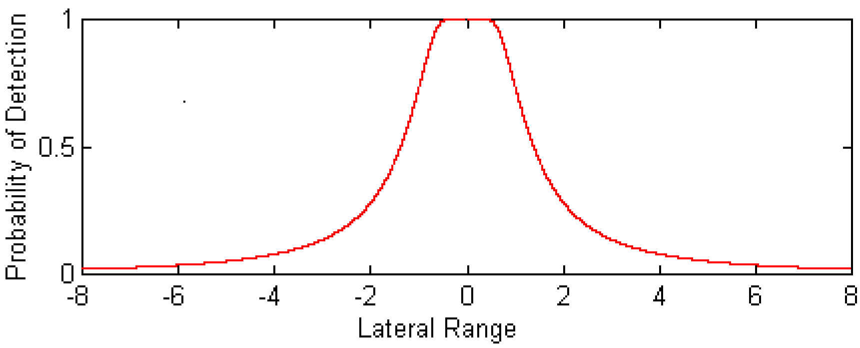

Figure 1 Example Lateral Range Curve

Koopman (1946) derived this particular relationship from the physical geometry of an aircraft flying over the ocean in search of an object on the surface. Negative values are distances to the left of the searcher's track while positive values are distances to the right of the searcher's track.

Visual search (as anyone looking for their keys knows) is highly dependent on distance. At first one would think that the important measure in any detection is the actual range at which the detection takes place. This begs the question of what range should be assigned to a non-detection when the searcher passes the object without detecting it. The answer is that the non-detection took place at all ranges down to and including the closest point of approach (CPA) or the "lateral range" value. It is also true that an object may be detectable for some time before it actually ***is*** detected. That is, detections may occur at any distance between the point where the searcher first gets close enough to make detection possible down to the CPA and then beyond to where detection is no longer possible. Therefore, both detection and non-detection events will be referenced to the lateral range or off-track distance.

Auditory search is also highly dependent on distance. However, it differs from visual search in that it is possible to know the distinct distance for each and every auditory attempt. It is also possible to determine if each auditory attempt of the team (whistle blast) was detected or not detected. This unique feature allows analysis using both the closest point of approach (CPA) and to determine an alternate detection index from each discrete detection opportunity. The second approach is called the "cone" approach since each detection opportunity was performed a traffic cone set on the course.

The lateral range method also functions as a natural integrator of the effects various factors have on the detection process during the experiment. Even in a fairly constant environment many factors may affect detection. The searcher may look elsewhere just at the time the object appears in an opening in the vegetation; wind or rain may affect hearing at a particular point; one searcher may have better scanning technique or eyesight than another; or the object may require several glimpses to register on the consciousness of the searcher, especially if it has a low contrast with its surroundings. For each searcher participating in a detection experiment, the lateral range concept makes detection data collection a matter of answering a simple question: "Did the searcher detect the object as he/she passed it or did the searcher not detect it?"

2.3 Detection Index (Effective Sweep Width)

Detection Index or s*weep width* is one of the central concepts of search theory and its application to SAR. The term *detection index* has a specific mathematical definition different from what one might infer from the usual meanings of its component words. Therefore, we should discuss the term at least briefly before proceeding further and provide at least one or more informal definitions. References to more complete and mathematically rigorous discussions will be provided.

The detection index is a single number characterizing the average ability of a given sensor to detect a particular search object under a specific set of environmental conditions. Thus each combination of sensor, search object, and set of environmental conditions will have a particular associated detection index. In the vernacular, detection index might be called a measure of "raw detection power." Loosely paraphrasing Koopman (1980), detection index may be described as follows:

Consider a sensor moving with constant velocity through (or over) a swarm of uniformly distributed, identical, stationary search objects under constant environmental conditions. If the average number of objects detected per unit time is divided by the object density (average number of objects per unit area), the resulting value is called the *effective search or sweep rate*. It is easy to see that the effective sweep rate has dimensions of area over time (e.g. square kilometers per hour). Dividing the effective sweep rate by the speed of the sensor gives the *effective search or sweep width*, which has units of length.

Notice that the above description does not imply that every object in the "swept area" is detected. Indeed, the meaning of "swept area" itself is not clear. To clarify how the term *sweep width* got its name, we will give an alternative description (also loosely derived from Koopman, 1980):

Consider an omni-directional sensor that is "perfect" (i.e. 100% effective) within some definite range and completely ineffective beyond that range. That is, detection is guaranteed for any object the sensor approaches more closely than the definite detection range, and the sensor never detects any object beyond that range. This idea is analogous to setting a lawn mower's blade to a height of zero and then pushing it into tall grass. The lawn mower would leave behind it a swath of bare earth having a definite width (twice the definite detection range), while blades of grass outside this width would be untouched. Inserting this particular sensor into the previous description, it is easily seen that in this special case (and this special case alone), the sweep width is literally the width of the swept area where the detections took place, i.e. twice the definite detection range. The concept is generalized by defining the *effective sweep width* of any sensor as equal to the sweep width of a definite range sensor that detects the same number of objects per unit time as the given sensor does under identical circumstances (i.e., same sensor speed, same object density, same environmental conditions). Generally the word *effective* is dropped, shortening the term to just *sweep width*. This is sometimes a source of confusion to new students of search theory and also to search planners in the field. Part of the reason that the term detection index is now preferred by many in the field.

We see that in only one situation, namely definite range detection, does the detection index actually correspond to a physical, geometric width measurement. Otherwise, it is a more abstract concept, but nevertheless one of great value and utility on both the theoretical and operational fronts. Additional treatments of the sweep width concept, some with illustrations, may be found in Koopman (1980), Stone (1989), and Frost (1998c, 1999b).

Unfortunately, sweep width cannot be measured directly for cases other than definite range detection. This is one reason why it is difficult to explain. Another reason is the ease with which the term "sweep width" is confused with other, sometimes similar, terms that have quite different meanings and uses. We will now attempt to rectify this problem by giving several different, but equivalent, descriptions of what detection index represents.

For all of the following descriptions, assume that search objects are uniformly, but randomly, spread over an area. Search objects in the context of sound line experiments represent conscious subjects willing to respond when they hear a whistle blast. A uniform random distribution means that the search object locations occur at random so their positions cannot be predicted, but the number of objects per unit of area is about the same everywhere. Also assume that the area covered with objects is very large compared to the maximum detection range.

Suppose an experiment was done where every searcher detected every object within a given lateral range, say 50 meters either side of the searcher's track, and detected no objects outside that range. That is, the searchers were 100% effective within 50 meters on either side of their track, and completely ineffective for objects farther from the searcher's track. This would constitute a "clean sweep" of a swath 100 meters wide with no detections outside that swath. The effective sweep width in this case would be 100 meters. In this "ideal" but unrealistic example, the effective sweep width is the same as the width of the swath where objects were detected.

Now suppose another experiment is done in another venue using the same number of objects per unit of area. Further suppose that the searchers in this experiment hear subjects that are up to 100 meters either side of their tracks, but they detect, on average, only half the objects located in that swath of 200 meters. Note that there will be twice as many objects in a 200-meter swath as in a 100-meter swath of the same length. Therefore, even though the searchers detect only half of those present in the 200-meter swath, they will detect just as many objects in one pass as the searchers in the previous experiment did. In this sense the two groups of searchers performed equivalently despite any differences in terrain, vegetation, searcher training, etc. So, for purposes of estimating how many objects will be detected in one pass, we would say the *detection index* in both cases was 100 meters. That is, both groups of searchers detected the same number of objects as lay in a swath 100 meter wide even though only the first group did this in a literal sense.

This illustrates the difference between detection index and maximum detection range. While it is possible to say that the width of the swath where searchers *can* detect objects will normally be about twice the maximum detection range, there is no way to predict from that information alone how many of the objects present in that swath *will* be detected, even if the number of objects present per unit of area is known. The detection index, on the other hand, does allow us to estimate how many detections we should expect provided we also know the number of objects present per unit of area. Simply multiply the effective sweep width by the length of the searcher's track to get the area effectively swept then multiply this value by the number of objects per unit of area to get the number of detections that should be expected. Note that this value does not depend in any way on the maximum detection range and there is no known mathematical relationship between the two. Having a maximum detection range in one situation that is twice that of another situation does *not* mean objects in the first situation are twice as detectable, on average, as objects in the second situation. In fact, it is actually possible that a small, high-contrast object might have a very large maximum detection range in a given environment under just the right circumstances but be less detectable on average in that environment than a larger object with less contrast and a smaller maximum detection range. Knowing the maximum detection range does not help with POD estimation. The maximum detection range during the sound experiments were well over 1000 meters, but the detection index was much lower. Also note that just as knowing the maximum detection range does not tell us the detection index, knowing the detection index provides no information about the maximum detection range (other than the maximum detection range will be larger). However, knowing the detection index gives us a way to reliably estimate POD since it is a measure of expected detection performance.

The detection index may be thought of as the width of the swath where the number of objects *NOT detected inside* the swath are equal to the number of objects that *ARE detected outside* the swath. That is, when one gets to the point where the number of objects missed within a certain distance either side of track (areas B above the curve in **Figure 2**) equals the number that are detected at greater distances from the searcher's track (areas A below the curve in **Figure 2**), then one has found the effective sweep width.

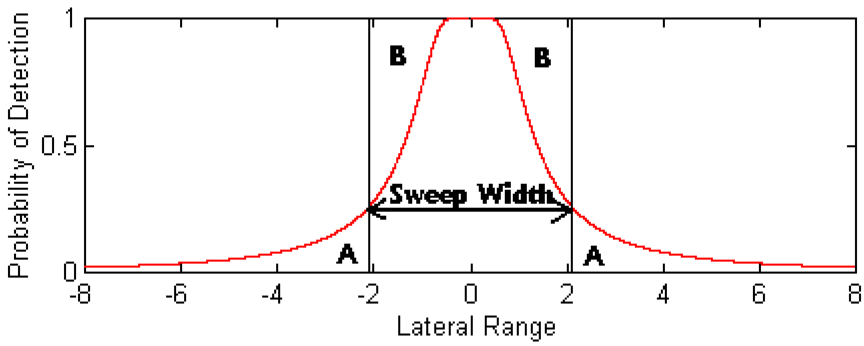

Figure 2 A Lateral Range Curve. The number of missed detections (B) inside the effective sweep width equals the detections (A) that occur outside the sweep width. This is often called the cross-over point.

For the more mathematically inclined who are familiar with calculus, the detection index is also numerically equal to the total area under the lateral range curve down to the horizontal axis of the graph. One way to estimate detection index from experimental data is to analyze the detection/non-detection results to first get an estimate of the lateral range curve and then compute the area under that curve. However, this is significantly more difficult than some other data analysis methods. This technique can be used when the experiment does not generate sufficient data to determine exactly.

Finally, if detection were perfect (100% POD) within a swath of width *W* and completely ineffective (0% POD) outside that swath, then the detection index width would be *W*. That is, if a "clean sweep" were possible with no detections outside the swept swath, the width of the swath would be, by definition, the detection index. Sensors with perfect detection within some definite maximum detection range and perfectly sharp cutoffs at that definite maximum detection range do not exist. However, this perspective on sweep width reveals another important property: The detection index value can never exceed twice the maximum detection range. It is almost always considerably less than that value, but just how much less depends on the search situation and all the factors affecting detection. It is not possible to establish any general mathematical relationship between a single maximum detection range and detection index.

Figures 3, 4, and 5 below illustrate the concept of detection index in another way. The black dots in **Figure 3** represent identical search objects that have been scattered randomly but approximately uniformly over an area. The distribution is "uniform" because in any reasonably large fraction of the area there are about the same number of objects as in any other fraction of the same size. The distribution is "random" because the exact location of each object was chosen at random to avoid producing either a predictable pattern or a bias favoring one portion of the area over another.

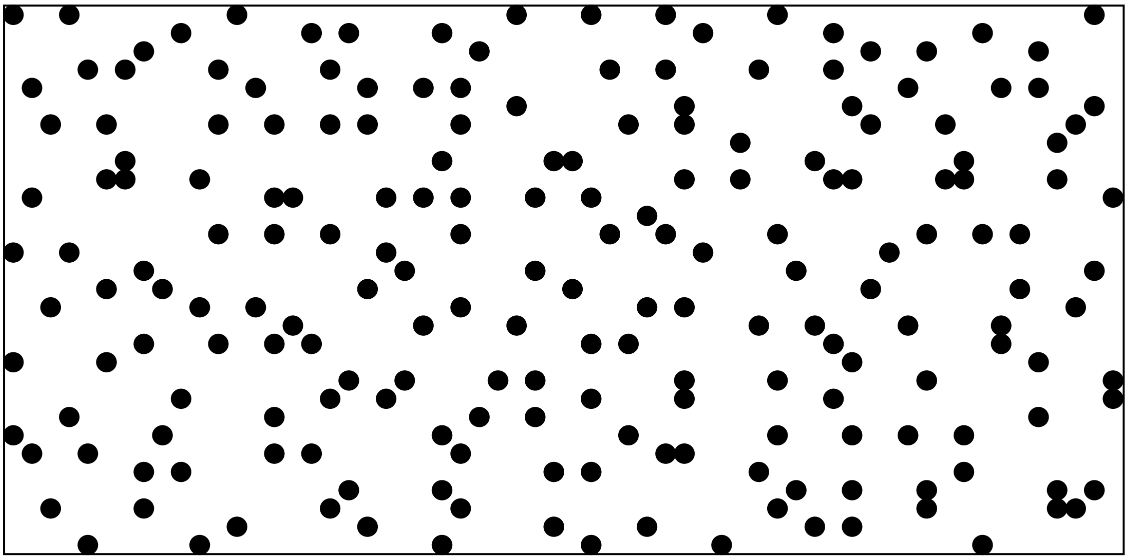

Figure 3 A Uniform Random Distribution of Search Objects

Figure 4 shows the effect of a "clean sweep" where all of the objects within a swath are detected and no objects outside the swath are sighted. In this case the detection index is literally the width of the swept swath. A total of 40 objects lay within the sweep width and all 40 were detected, as indicated by the empty circles. A "clean sweep" where the searcher/sensor is 100% effective out to some definite range either side of the track is unrealistic, but it serves to illustrate the detection index principle.

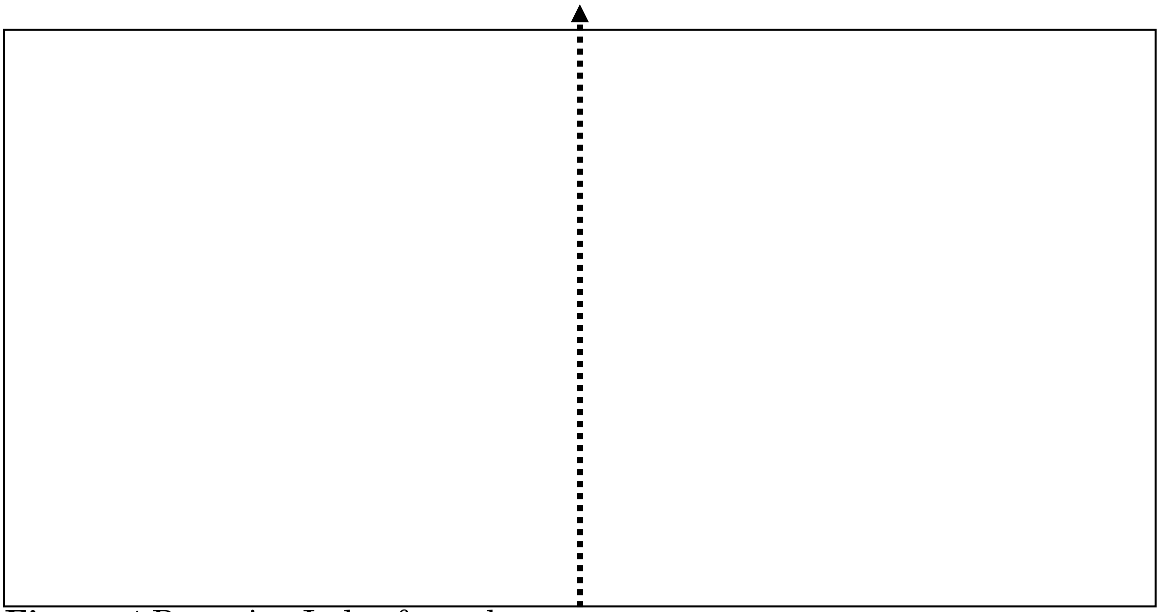

Figure 4 Detection Index for a clean sweep.

Figure 5 represents a more realistic situation where objects are detected over a wider swath, but not all the objects within that swath are found. In this case, the total number of objects detected was also 40 but instead of making a "clean sweep," the detections are more widely distributed. However, because in both cases 40 objects were detected over the same length of searcher track when the number of objects per unit of area was also the same, we say the *effective* sweep widths or detection index for both cases are equal.

Detection index is a measure of detectability because, in a hypothetical situation where the average number of objects per unit of area is known, if we know the detection index we can accurately predict how many of the objects will be found, on average, by single searchers (or if the detection index was determined for a "team" then we can predict team results) on one pass through the area. As we will show later in this report, knowing the detection index for a given combination of sensor (e.g., visual search), search object (e.g., a person) and environment (weather, terrain, vegetation, etc.) will allow us to accurately predict the probability of detection for any search conducted under those or similar conditions.

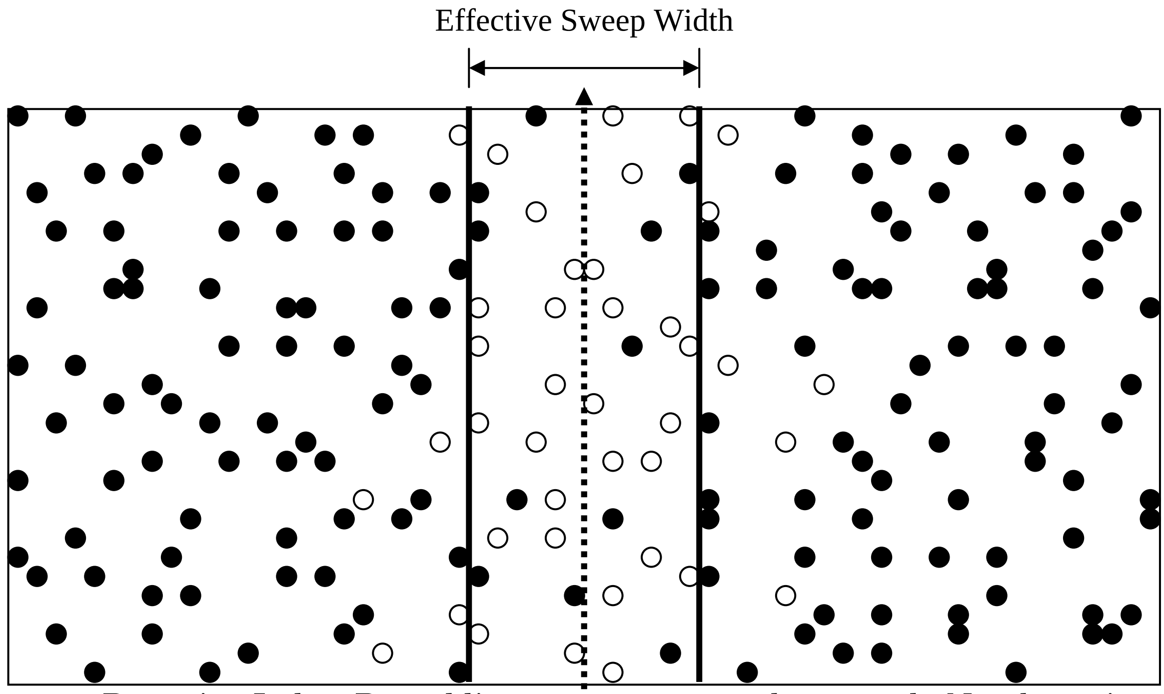

Figure 5 Detection Index. Dotted line represents searcher's track. Number missed within detection index = 11. Number detected outside detection index = 11.

Figure 5 also illustrates the property of detection index where the number of undetected objects inside the swath equals the number of objects detected outside that swath.

To summarize: Detection index is the metric used for estimating an object's detectability for a given search scenario. It is a single number having the dimensions of length. It may be derived from the lateral range curve that is produced from detection/non-detection data of an experiment that is appropriately designed and performed. It has the property that, on average, the number of search objects detected outside the detection index is numerically equal to the number of search objects not detected within the detection index. It is used together with the amount of effort expended in a given area (e.g., a search segment) and the size of the area to get an objective, reliable, and accurate estimate of POD.

As a practical matter, it is not possible to directly "measure" detection index at the place and time of a search. It is also impossible to develop detection index values for the infinitely many possible combinations of sensor, search object, and environmental conditions. The US Coast Guard has addressed these problems by designing and conducting numerous experiments to gather empirical data from which operationally useful detection index estimates may be inferred. The Coast Guard's Research and Development Center has been conducting such experiments for more than twenty years, identifying the significant variables affecting operational detection indexes in the marine environment and producing extensive detection index tables indexed to these variables. These tables are published in the U. S. *National SAR Supplement* (National Search and Rescue Committee [NSARC], 2000) and in a simplified derivative form in the *International Aeronautical and Maritime Search and Rescue Manual* (ICAO/IMO, 1999a-c). These simple tables allow the user to choose appropriate conditions and correction factors to provide the best estimate of the detection index. Once a detection index is obtained it is relatively straight-forward to determine the POD.

2.4 "Effort" and "Search Effort" (Area Effectively Swept)

Effort is a measure of resource expenditure and may be defined as the amount of distance covered by the searcher(s) in a search segment while searching. It could be measured in several ways, but the usual metric for search theory purposes is the distance a sensor platform travels while in the search segment. A search segment is defined as some bounded geographic area that a particular resource, such as a team of searchers, has been assigned to search. The distance a searcher covers while searching may be estimated by either estimating or recording the amounts of time spent searching (exclusive of rest or meal breaks, transit times to and from the assigned segment, etc.) and multiplying that value by the estimated average search speed using the familiar formula,

$$d = rt$$

for ***d***istance equals ***r***ate times ***t***ime. When a team of searchers is assigned a given segment, the total distance traveled by all members of the team will be needed. This value may be found by summing all the individual team member distances or, if all members moved at about the same speeds for about the same amounts of time while searching, then the distance covered by one searcher could be multiplied by the number of persons in the team to get the total distance covered in the segment. That is,

$$Effort = \sum_{i=1}^{n} d_i \text{ or } Effort = nd$$

where n is the number of searchers on the search team.

Search effort is a measure of how much "effective" searching is done by the sensor as it moves through the search area. *Search effort* is simply the product of the detection index and the distance the sensor travels while in the search area or:

$$Area\,Effectively\,Swept = Effort \times DetectionIndex$$

It is easy to see that *search effort* has units of area. It is often called *area effectively swept*.

This computational step is required if calculating the POD for a sound or sound-light sweep tactic. In the sweep tactic the team is composed of many searchers essentially searching independently (although organized into a controlled line that moves forward). The number of searchers packed into an area along with the number of passes the team makes in the area clearly has a direct impact on the amount of search effort.

For a sound or sound-light line tactic the area effectively swept is equal to the length of the task multiplied by the detection index. This will allow the coverage formula to be simplified for sound or sound-light line calculations.

2.5 Coverage

Coverage (sometimes called *coverage factor*) is a relative measure of how thoroughly an area has been searched, or "covered." *Coverage* is defined as the ratio of the area effectively swept to the physical area of the segment that was searched:

$$Coverage = \frac{Area\ Effectively\ Swept}{Segment's\ Area}$$

It is possible to simplify this equation for sound – light line search tactic since the components of the effort are canceled out by components of the Segment's Area.

$$Coverage = \frac{TrackLineLength \times Team \times DetectionIndex}{TrackLineLength \times Offset \times 2}$$

Since in a sound-light line search, the team simply counts as one team (initial pilot experiments were conducted with teams of two), the team or number of searchers may be removed from the equation. In addition the TrackLineLength cancels out from both parts of the equation. This leaves coverage being determined by only the detection index and the offset. The offset is the distance away from the track that the search planner is interested in as defining as the search area. Of course the actual area is defined on both the left and right side of the track so it is multiplied by two. While it is still possible to define a sound-light line search area like other area based search areas, a more meaningful method is simply a fixed distance away (track offset) from the linear featured being used to conduct the search. This gives the final equation that follows:

$$Coverage = \frac{DetectionIndex}{Offset \times 2}$$

Searching an area and achieving a *coverage* of 1.0 therefore means that the *area effectively swept* equals the area searched. For a sound-light line defining the offset to equal the half the detection index would also give a coverage of 1.0. Note that this does not necessarily mean that every piece of ground "covered" nor does it mean that the POD of a coverage 1.0 search is at or near 100%. Coverage is a measure of how "thoroughly" the segment was searched. The higher the coverage, the higher the POD will be. However, the relationship is not linear. That is, doubling the coverage does not double the POD. **Figure 6** (POD versus Coverage curve) shows the relationship between coverage and POD as derived by Koopman (1946, 1980) for situations where searchers do not move along a set of long, perfectly straight, parallel, equally spaced tracks but instead follow more irregular paths. Other curves also exist. It remains to be found, after additional experiments, if the other curves are better predictors of POD for sound-light lines since the teams are traveling among a fixed linear path.

It is important to always remember that coverage and the corresponding level of effort are proportional. To double the coverage it is necessary to double the level of effort and doubling the level of effort doubles the coverage. In other words, although the relationship between POD and coverage is not linear, the relationship between coverage and effort is. This means, by extension, that the relationship between effort and POD is not linear, either. Doubling the effort assigned to a segment will not generally double the POD.

Since terrain and vegetation often prevent ground searchers from following a mathematically precise pattern of parallel tracks, and since ground searchers frequently alter their tracks to investigate possible sightings, look behind major obstructions, etc., the exponential detection function, as the curve in **Figure 6** is called, seems to be the most appropriate for estimating ground search POD. For auditory searches the terrain, wind, size and type of vegetation, and differences in hearing ability introduce many random variables. This curve also works well when other "random" influences are present. The equation of this curve is

$$POD = 1 - e^{-Coverage}$$

where *e* is the base of the natural logarithms (approximately 2.718282). The function e^x or EXP is available with most handheld scientific calculators and electronic spreadsheet programs.

It can be seen that *coverage* is proportional to *search effort density*, the constant of proportionality being the *detection index.* Therefore, any solution to the optimal search density problem is also a solution to the optimal coverage problem. In this sense, the two terms may be used interchangeably when discussing optimal search plans.

2.6 Probability of Detection (POD)

The probability of detection (POD) is defined as the *conditional* probability that the search object will be detected during a single sortie *if* the search object is present in the area searched during the sortie. Cumulative POD (POD_{cum}) is the cumulative probability of detecting the search object given that it was in the searched area on each of several successive searches of that area. Like coverage, it is a measure of how thoroughly an area was searched. The relationship between coverage and POD is usually plotted on a graph of POD vs. Coverage. Such a graph appears in **Figure 6**.

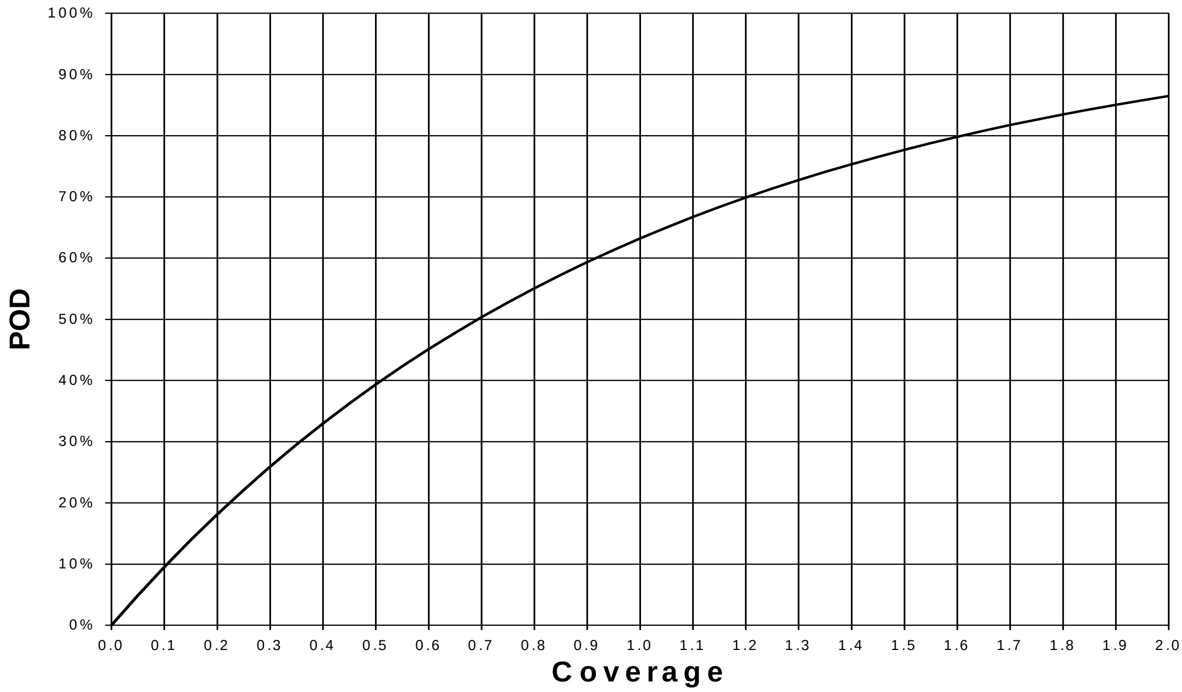

Figure 6 POD versus Coverage (Koopman, 1946)

POD in itself is not the goal of search planning as some of the land search literature has suggested. POD is merely one part of a larger system.

Factors that influence Sound Detections

Weather

- Wind Speed
- Wind Direction
- Barometric Pressure
- Humidity
- Temperature

Sound Source

- Whistle Type (frequency – range)
- Whistle Aim
- Whistle Duration
- Shout duration
- Shout loudness
- Shout frequency response

Environment

- Terrain
- Ground Cover
- Diameter of Trees
- Reflections
- Absorptions
- Background Noises (water, leaves)

Sound Detection

- Hearing (loss)
- Direction Pointing
- Hood, cap, etc
- Attention
- Fatigue, moral
- Temporary hearing loss

Part III – Experiment Results

6. Description of Venue – Nelson Lakes St. Arnaud

6.1 Location

Nelson Lakes National Park (established in 1956) is situated in the north of New Zealand's South Island. This park protects 102,000 hectares of the northern most Southern Alps. The park offers tranquil beech forest, craggy mountains, clear streams and lakes both big and small.

During the last Ice Age massive glaciers gouged out troughs in the mountainous headwaters of the Buller River. Today these troughs are filled by Lakes Rotoiti and Rotoroa, which give the Park its name. They are the largest lakes in the area.

Craggy mountains surround the lakes. The vegetation is predominantly beech, with the red and silver species growing in lower, warmer sites and mountain beech at higher altitudes. The bush line, where forest gives way to alpine plants is a remarkable feature of the park; the change is abrupt and uniform as if drawn with a ruler. In summer the alpine fell fields teem with flowers, though typically they tend to be pale colours, white, light blue and sometimes yellow.

The forests are full of birds like tomtits, robins and the tiny rifleman, New Zealand's smallest bird. South Island kaka are also present. A highlight in the park is the Rotoiti Nature Recovery Project, which aims to create a pest-free refuge in the honeydew beech forests beside Lake Rotoiti paving the way for the recovery and re-introduction of native species in the area. It also provides an ideal opportunity for the public to see conservation work at first hand, and for people to enjoy and appreciate New Zealand's unique natural attractions. While similar restoration efforts have been made for years on New Zealand's offshore islands, the 5000 ha Rotoiti Nature Recovery Project is part of a national programme aimed at extending these successes onto the mainland through the creation of island-like refuges, known as 'mainland islands'.

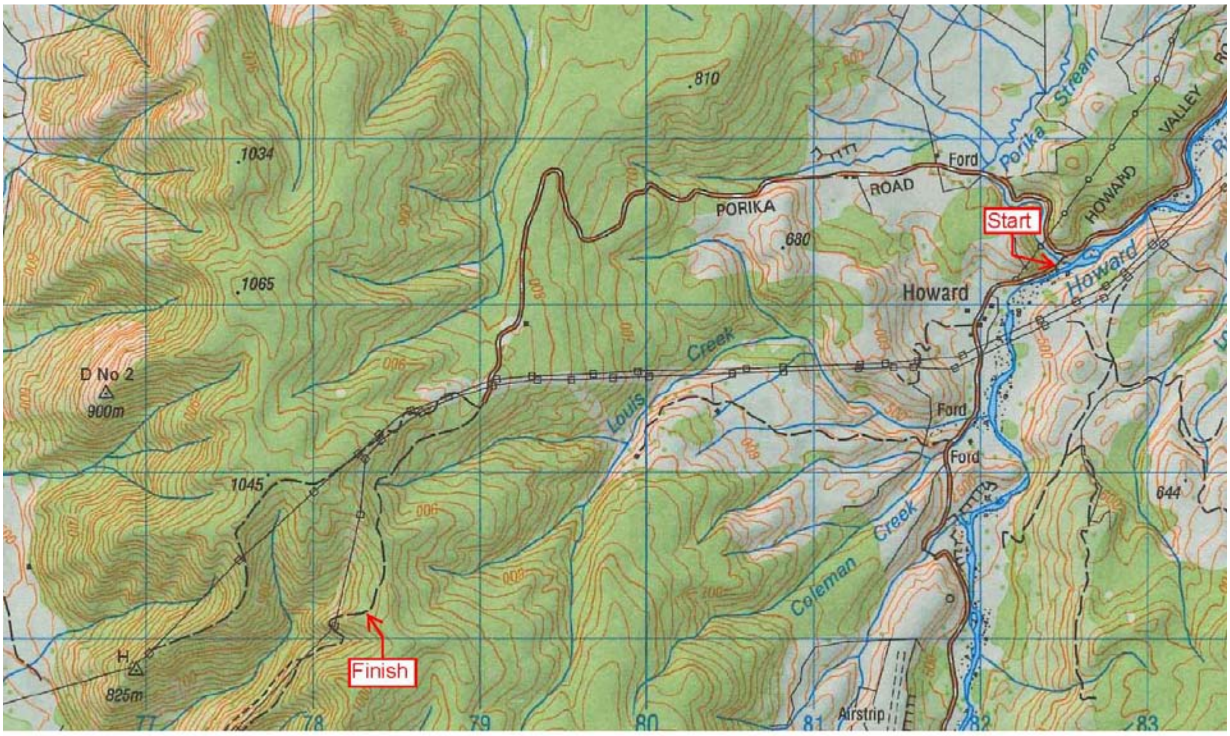

Figure 17 Topographic map of search track

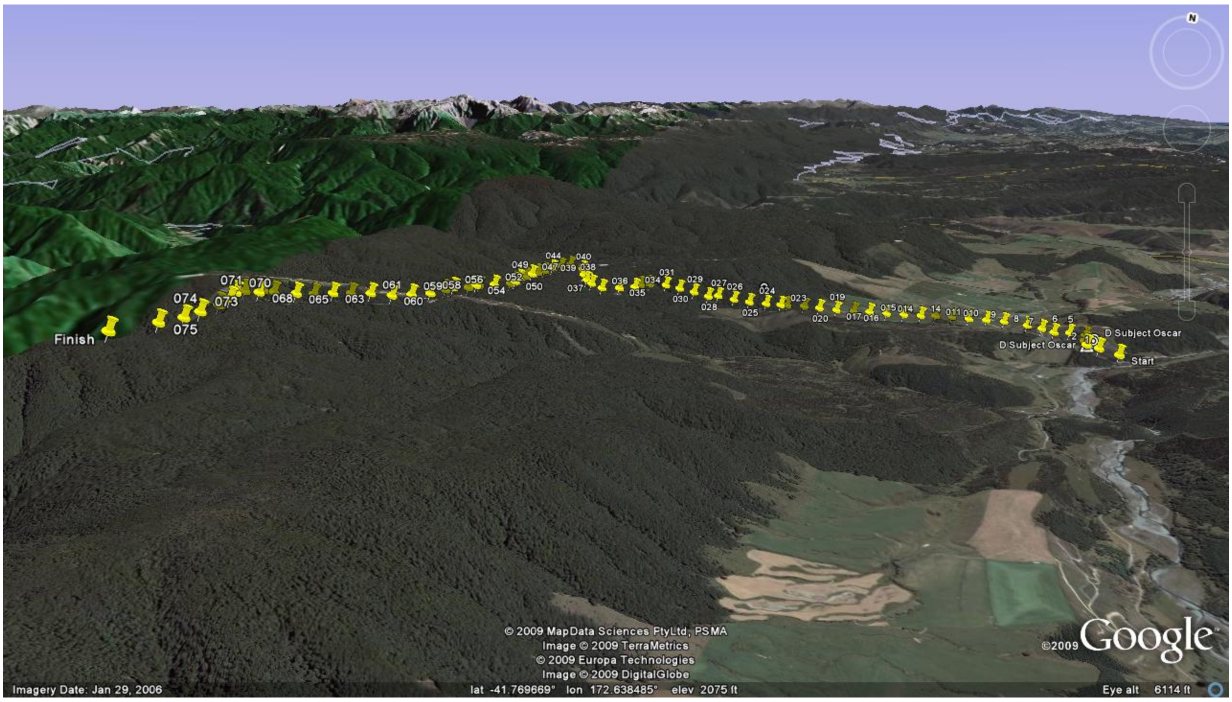

Figure 18 Google Earth view of search track with cone locations plotted

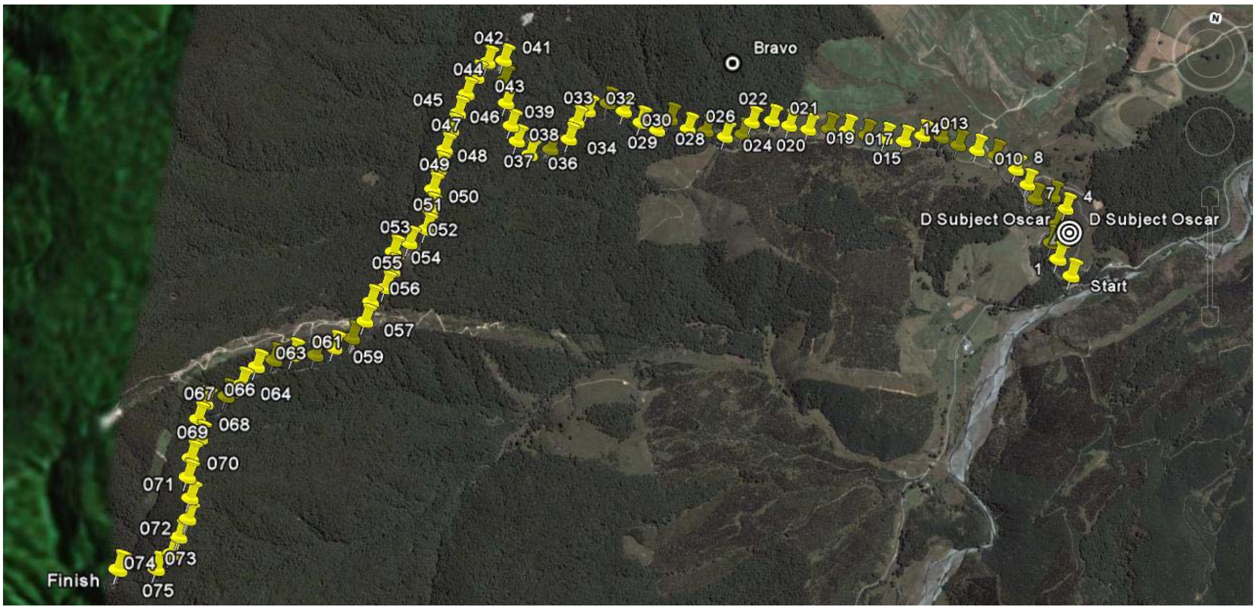

Figure 19 Google Earth top down view

6.2 Course Selection Discussion

The general location was chosen due to the willingness and dedication of Sherp Tucker of the Tasman Police District to coordinate the logistics of the pilot experiment. The initial guidelines given for potential site location was the following:

- Track or road of 5-10 kilometers in length
- A road would be slightly more ideal to assist with logistics
- If road lightly travel or able to control traffic
- Able to find a staging area for parking in close proximity
- Ideal if a loop
- Track goes through homogenous vegetation and terrain
- Track should be representative of what might be covered by a sound-light line tactic during an actual search incident.
- Participants can arrive by vehicle. Access should not require any excessive off-road driving

In a collaborative effort between Tony Wells, Sherp Tucker, and Ross Gordon two potential sites were identified for site visits. Both potential sites were visited with the second site (Porika Road in the Nelson Lakes region) selected as the most appropriate. The site was able to be reached easily off Route 63. While Porika Road did not form a loop, it was easy to drive (with a good four-wheel drive vehicle) and had several locations where vehicles could pass. In addition, during the site visit on July 3rd, AMDR measurements were taken.

Setting up the course, went largely as planned. The starting point was moved from higher up the road to the intersection of Porika Road with Howard Valley Road. This both simplified logistics and made for a longer track. On July 17th the experiment team arrived to start setting up the track. As previously described the track was measured and marked every 100 meters and cones placed. This was accomplished by one person walking the course and the cone placement team following in a vehicle which carried all of the cones, fibreglass rods, and gloves. Placement of the last cone occurred at dusk.

6.3 Participant Recruitment

The Nelson Lakes experiment was a dedicated experiment event held at Nelson Lakes. Participants were recruited mostly by Sherp Tucker with some additional participants recruited from the Canterbury district by Tony Wells. All searchers belonged to a search team or played an active role in search and rescue.

7. Primary Results

Two separate experiments were carried out at Nelson Lakes on July 18 and into the early hours of July 19, 2009. The first experiment occurred during daylight and only looked at the sound line tactic. The second experiment occurred after dark. New subjects were placed in different locations. The night time experiment involved both sound and light line tactics. For each experiment the detection index can be determined by using the Closest Point of Approach (CPA) technique or from each cone's position. In addition, to determining the overall detection index for the teams hearing a response from the searcher, it is also possible to determine the detection index for the subject hearing (whistle blast) or seeing (flashlight during the night experiment) the search team. Finally, one of the subjects had a profound hearing loss (70% hearing loss). His results were not included in the overall results. Instead, it was treated as a separate experiment.

7.1 Course Characteristics

Table 7.1 provides the general characteristics of experiment conducted at Nelson Lakes.

	Day	Night
Location	Porkia Road, Nelson Lakes	
Ecoregion	Mountainous Subtropical M230	
Season	Winter	
Event	Dedicated Experiment	
Length	7.5 km Bottom to Top	7.5 km Top to bottom
Elevation change	1531 – 3225 feet (1694)	
Layout	Road	
Temperature	10-12 C	1-5 C
Wind	0-10 kph	2-45 kph
Cloud cover	Partly Sunny	Clear – Foggy
Visibility	Unlimited	Unlimited – 200 meters
Precipitation	None	Rain – Moderate
Pressure	943 mb falling	935 mb falling

.

7.2 Day time Experiment

The day time experiment started at 11:28 with team one and ended at 17:57 with team fourteen. The original methodology called for each member of the two person teams to collect a separate detection log. However, due to a printer's error not enough detection logs were printed. In addition, the first two teams dispatched were given an incorrect briefing. Therefore, only team three generated two detection logs. This brought the total number of "teams" to 15.

The day time experiment in addition to live subjects placed at various lateral ranges also had clues placed on the track. The clues consisted of either high visibility clues or low-visibility clues. The high-visibility clues were white workers gloves painted with day-glo orange dazzle, and the low-visibility clues were the same gloves painted gray. One low-visibility glove was left white, since it was placed on some snow. Searchers were informed to record any gloves they located. The gloves were all placed on either the left or right side of the track. Since it was foreseen that vehicles would be driving on the road, they were placed out of any ruts so they would not be driven over. The gloves did not represent a true detection index experiment since no lateral range was calculated. It was too difficult to determine exactly where search participants might be walking along the road for a meaningful placement off the gloves off the particular track. Instead, the purpose of the glove placement was a rough estimate for the POD when a clue might have a lateral range of zero and is found on the track itself.

7.2.1 Day time Experiment – Modifications to IDEA Placement

Seven subjects were placed during the daytime experiments. The subject placement was largely determined by the IDEA software. A few minor modifications where performed. The first subject (trackline distance 350 was initially suppose to be placed 200 meters lateral range. When it was learned that he suffered from a 70% hearing loss, he was directed to a lateral range of 40 meters. When he reported he heard none of the first four teams he was directed to move within 25 meters. Since he was on an upward slope, his actual distance worked out to be 20 meters. Subject Juliet's position was moved slightly to take advantage of a road that allowed easy access. The last subject (Mike) was squeezed in at the end of the class. The track took a slight curve, and this feature was taken advantage of to make sure the subject did not overlap with any other subjects.

7.2.2 Day time Experiment – Team Detection Experiment Results

The first detection index, which is perhaps the most important, is the ability of the team to detect the subject. This involved the team blowing its whistles at each cone. Then if the subject heard the whistle responding by shouting "Hey, its Bravo." If they team heard and recorded anything that sounded human they recorded a detection. All potential detections were cross-referenced with the actual locations of where subjects were placed. The first method of determining the detection index used the Closest Point of Approach method. This method resulted in 116 detection opportunities.

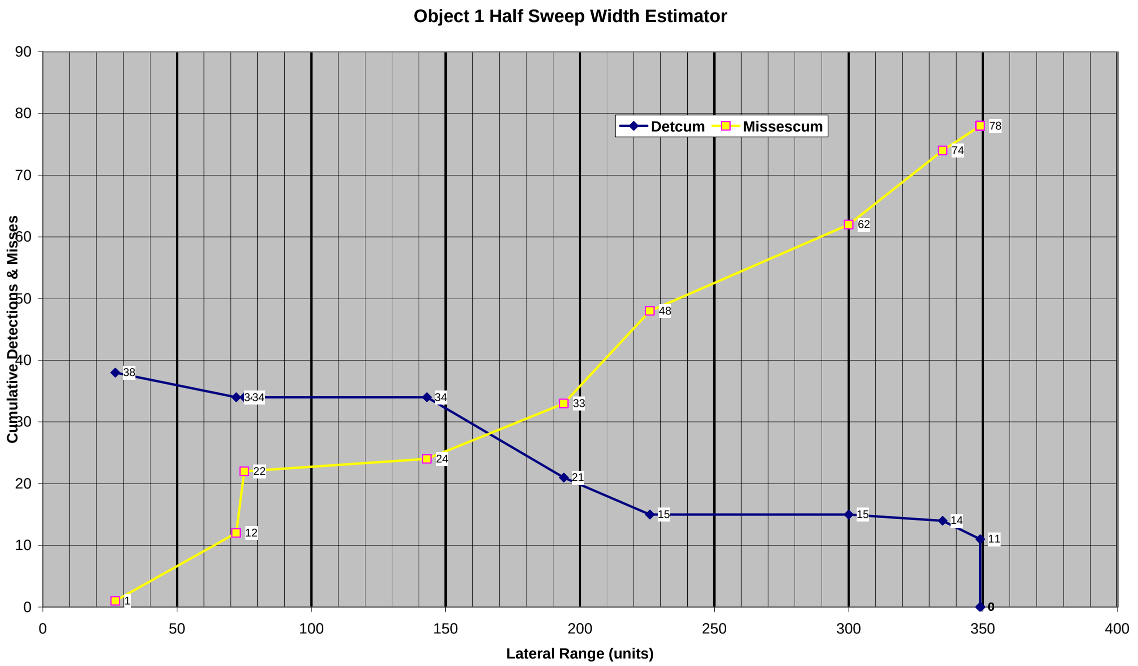

Figure 20 Cross-over graph for searchers detecting subject

The crossover technique gave a clean graph and a half detection index of 166 meters. Since in reality a search track has a left and right side, these results in a detection index of 332 meters.

The second method of detection involved measurements for each cone location shown in Figure 21.

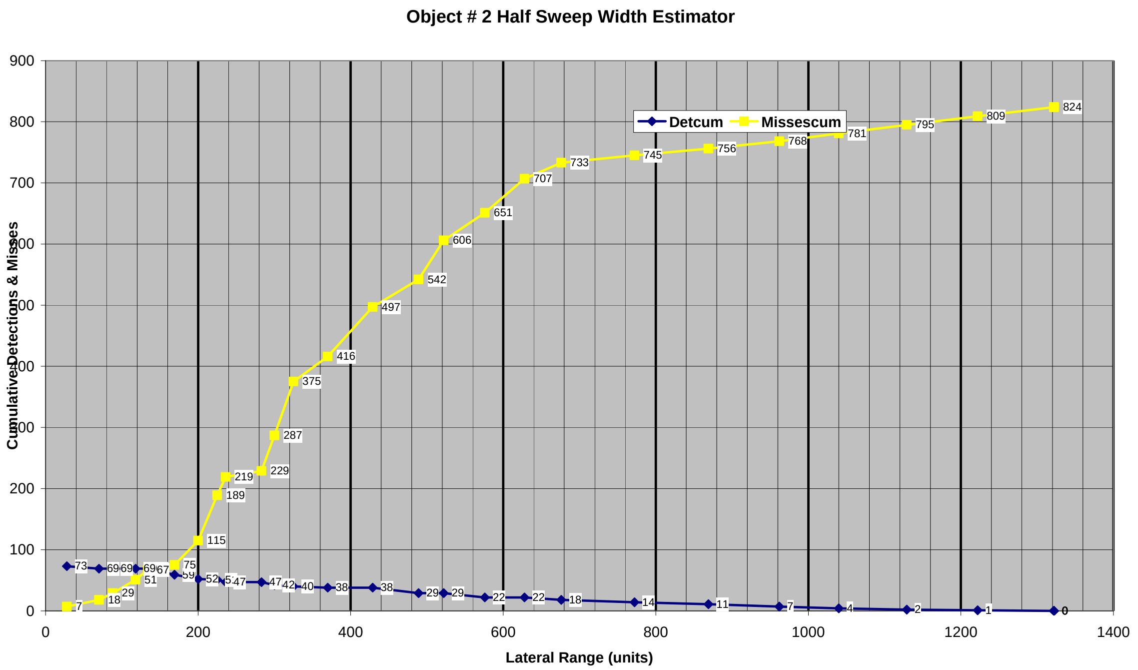

Figure 21 Cross over graph using cone method. Notice much greater distances

It can be seen from the graph that some detection occurred at over 1200 meters. All of these extended detections occurred with subject Bravo. Subject Brave was located on a slope and the extended detections occurred along the flat section of the road where no trees existed. The half sweep width value is 138 meters, but it is important to not the cross over occurred between the 134 and 169 meter bins. The full detection index value of 276 meters is 17% less than the CPA method of 332 meters. The two values should be viewed as quite close. The cone method involving over 824 detection opportunities turns out to be similar to the CPA method with 78 detection opportunities. This once again shows the sensitivity of the crossover method of data analysis.

7.2.3 Day time Experiment – Subject Detection Experiment Results

Since auditory search is a two-way search problem, it is also useful to determine the Subjects detection index of hearing the whistle blast. Scoring the subject's detections only used the CPA. It was impossible to determine which cone the team was located at during the whistle blast from the subject's perspective. In fact, it was difficult to score the subject's detection log even using the CPA approach. The first step in scoring was starting with the team detections. If the team heard the subject, then by default the subject had heard the team. The next phase was to determine if the subject had heard the team, even when the team did not hear the response. The trackline distance where most teams had heard the subject was recorded. Then in a separate worksheet the exact time each team reached that particular cone (trackline location) was recorded. Finally, the team's cone time was cross-referenced to the subject's detection log. If the two times matched then the subject scored a detection for that particular team. One team did not record their cone times so it was not possible to score that team.

In several cases it was observed that the subject in fact detected almost all of the teams. However, almost none of the teams detected the subject. This would result in a larger detection index for the subject detecting the teams. This is in fact the actual result. The team's detection index (CPA method) was 332 meters and the subject's detection index was 401 meters.

Location #	LR	Count	Detections	Misses	% Detected	Det_{cum}	$Misses_{cum}$
Charlie	27	5	4	1	80%	52	1
CharlieV1	72	10		10	0%	48	11
Mike	75	10	6	4	60%	48	15
Papa	143	14	14		100%	42	15
Romeo	194	14	5	9	36%	28	24
MikeV	226	14		14	0%	23	38
CharlieV2	300	14		14	0%	23	52
Juliet	335	14	9	5	64%	23	57
Bravo	349	14	14		100%	14	57
Check Sums		109	52	57			
Effective Sweep Width			**401**	Meters			

Figure 22 Subject detecting teams data.

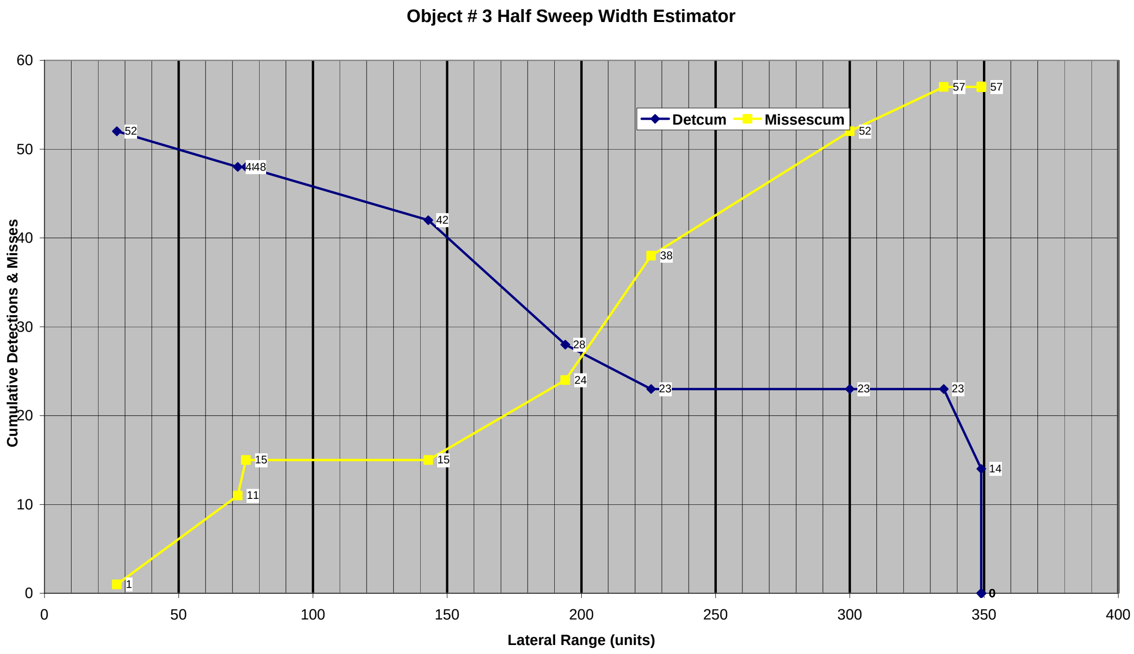

Figure 23 Cross-over for subjects detecting teams.

The graph shows a good cross-over event for the half- detection index estimate for a team making the detection.

7.2.4 Day time Experiment – Clue Detection

The clue detection experiment only took place during the day. The original intent was to conduct the clue detection experiment at night. However, experience has shown the course needs to be setup the day before. Therefore, the clues were placed (using IDEA to determine the locations) the previous day. A total of 12 orange gloves were placed, 11 gray gloves, and 1 white glove (placed on snow). Out of the 15 teams that turned in a detection log only 12 completed the log in such a way it was possible to score the clues.

	Number	Detection Opportunities	POD%	POD%
Orange Glove	12	144	99%	99%
Gray Glove	11	132	57%	52%
White Glove	1	11	0%	

Figure 24 Detection rates for clues on track

The last team (team 14) consisted of one of the officers who had help setup the course. He had specific knowledge about the white glove. Therefore, that particular glove from team 14 was thrown out. The range of POD% for the orange glove was 92% - 100%. The range of POD% for the low-visibility gloves was 25% - 83%.

The experiment was not repeated at night, since searchers would already have some idea where the gloves would be located. Some thought had been given to moving the glove locations between the day and night experiments. However, the last day team finished at dusk and insufficient time remained to find and then relocate the gloves. Therefore, the glove experiment was not repeated at night. In reality, with darkness, and the approach from an opposite direction, the detection experiment should have been repeated. Although, this might have slowed team down further, making the experiment take longer.

Figure 25 Creating a high-visibility glove

7.2.5 Day time Experiment – Hearing Loss

As previously stated subject Oscar had a known 70% loss of hearing. Therefore, his results were excluded from the detection index values. He was initially placed 50 meters off the track. Later he was moved to 25 meters off the track. Even at this distance he did not hear most of the whistles. He was in a position where he could see the teams blowing whistles, but still could not hear the signal. For the few teams where he could hear a whistle blast it is possible to calculate a detection index.

Looking first at the cross-over graph we can see the two lines do not cross.

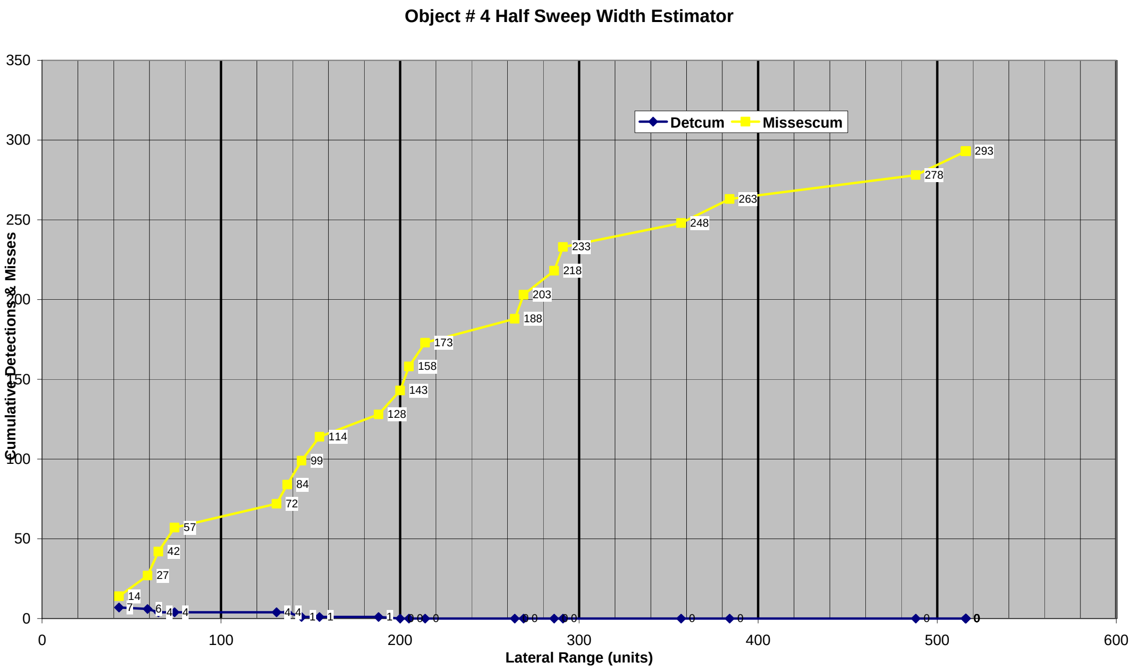

Figure 26 Failure to achieve cross-over for subject with hearing loss

Therefore, it is not surprising that an initial detection index of 0 meters is generated by IDEA.

Location #	LR	Count	Detections	Misses	% Detected
300	43	15	1	14	7%
400	59	15	2	13	13%
400	65	15		15	0%
300	74	15		15	0%
200	131	15		15	0%
500	137	15	3	12	20%
200	145	15		15	0%
500	155	15		15	0%
600	188	15	1	14	7%
100	200	15		15	0%
100	205	15		15	0%
600	214	15		15	0%
700	264	15		15	0%
0.1	269	15		15	0%
0.1	286	15		15	0%
700	291	15		15	0%
800	357	15		15	0%
800	384	15		15	0%
900	488	15		15	0%
900	516	15		15	0%
Check Sums		300	7	293	
Effective Sweep Width			**0** Meters		

Figure 27 Initial detection index of 0 since cross-over failed

Next looking at the lateral range (**Figure 28**), it is clear that very little area falls under the curve. In fact it is hard to estimate since no data exists within the 50 meter range.

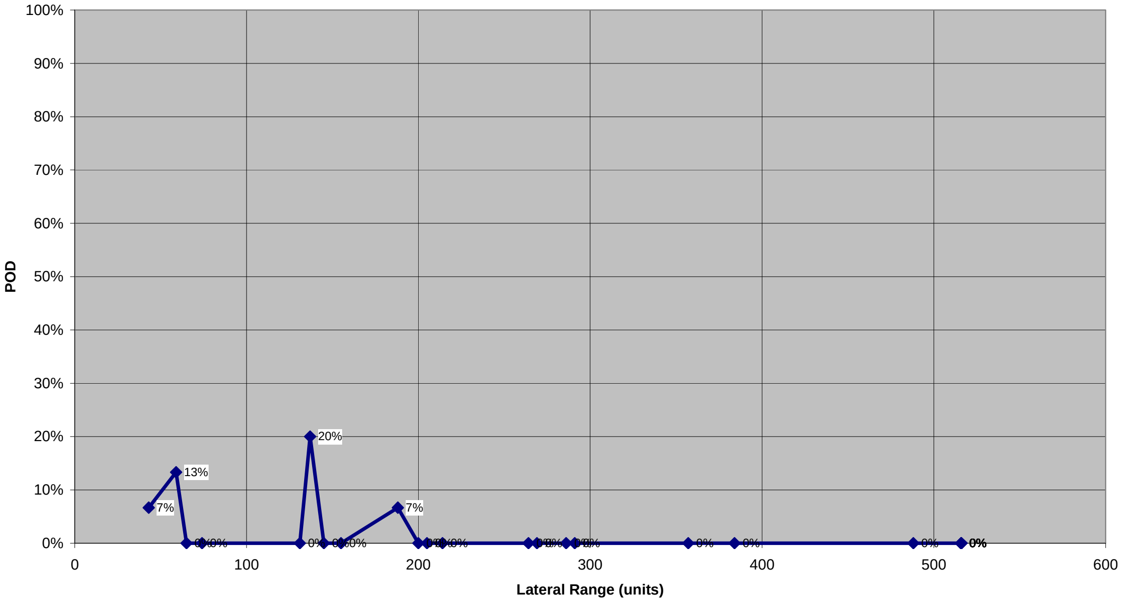

Figure 28 Lateral Range curve of subject with hearing loss

However, since the subject could understand a conversation from one-meter away. It is possible to assume that the detection rate at one meter would have been 100%. Making a virtual target at one meter lateral range and assuming 100% we achieve the following results.

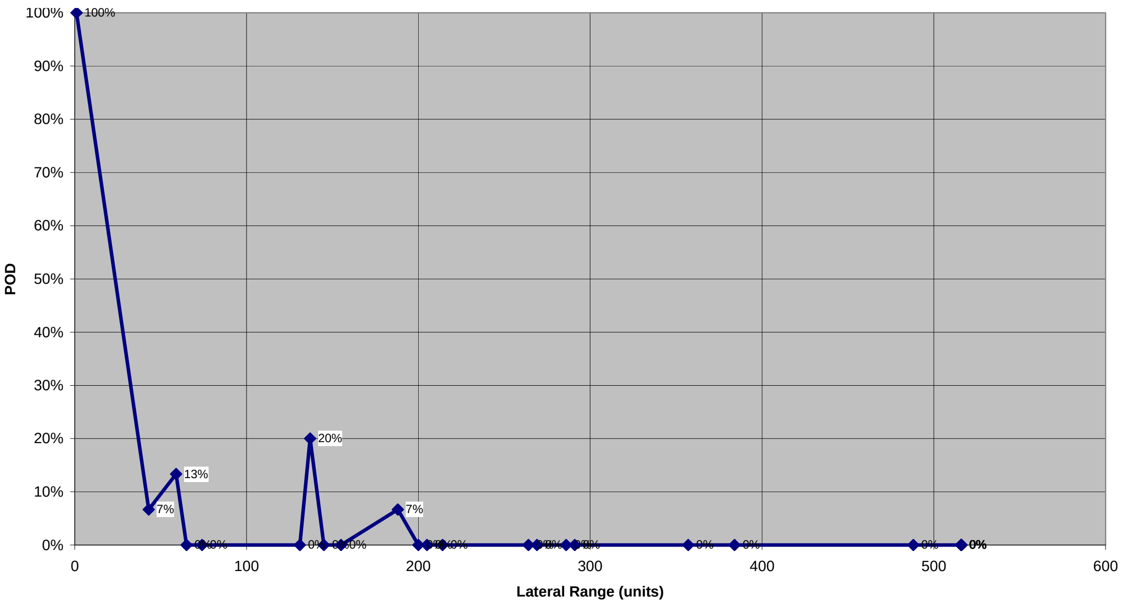

Figure 29 Lateral Range generated by assuming 100% detection at 1 meters

By starting at 1 meter with 100% detection the detection index changes to 66 meters

Location #	LR	Count	Detections	Misses	% Detected
350v	1	15	15		100%
300	43	15	1	14	7%
400	59	15	2	13	13%
400	65	15		15	0%
300	74	15		15	0%
200	131	15		15	0%
500	137	15	3	12	20%
200	145	15		15	0%
500	155	15		15	0%
600	188	15	1	14	7%
100	200	15		15	0%
100	205	15		15	0%
600	214	15		15	0%
700	264	15		15	0%
0.1	269	15		15	0%
0.1	286	15		15	0%
700	291	15		15	0%
800	357	15		15	0%
800	384	15		15	0%
900	488	15		15	0%
900	516	15		15	0%
Check Sums		315	22	293	
Effective Sweep Width			**66** Meters		

Figure 30 Detection index changes to 66 meters by adding 1 meter assumption

The 66 meter hearing impaired detection index is significantly less than the 276 meter detection index determined by the cone method. This would suggest a correction factor of 0.24. However, since each location had specific terrain and vegetation characteristics it might be more meaningful to make the comparison to another subject placed in the same general area. This was the actual case. During the night time experiment a second subject was also placed at track location 350 to the right of the track. However, this time the subject had putative normal hearing and was placed at greater distances. Using the cone method the detection index for subject Alpha was 186 meters. This would suggest a correction factor of 0.35

7.3 Night time Experiment

The night time experiment started at 20:36 with team one and ended at 01:34 with team ten. Teams consisted of two-person teams. While the glove clues were still present on the course, the teams were told to ignore the clues. Seven subjects were placed during the night experiments. The subject placement was largely determined by the IDEA software. A few minor modifications where performed. IDEA always places the first subject close to the start, this resulted in Alpha being placed at the same trackline distance as subject Oscar from the day experiment. Subject Quebec's position was moved slightly to take advantage of a road that allowed easy access. The last subject (Golf) was squeezed in at the end of the course. The track took a slight curve, and this feature was taken advantage of to make sure the subject did not overlap with any other subjects.

7.3.1 Day time Experiment – Team Detection Experiment Results

The first detection index, which is perhaps the most important is the ability of the team to detect the subject. This involved the team blowing its whistles at each cone. Then if the subject heard the whistle responding by shouting “Hey, its Alpha.” If the team heard and recorded anything that sounded human they recorded a detection. All potential detections were cross-referenced with the actual locations of where subject’s were placed. The first method of determining the detection index used the Closest Point of Approach method. This method resulted in 80 detection opportunities with a detection index of 306 meters.

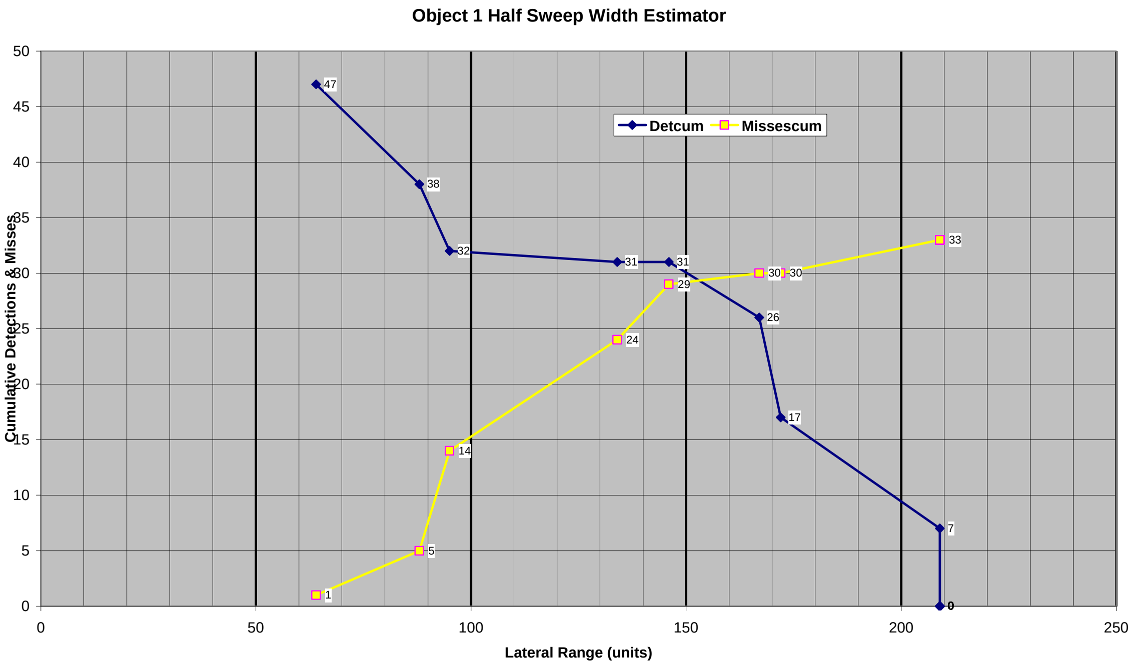

Figure 31 Cross-over graph of team detection at night

The cross-over graph had a clear cross-over point. While the lateral range curve was not as clear.

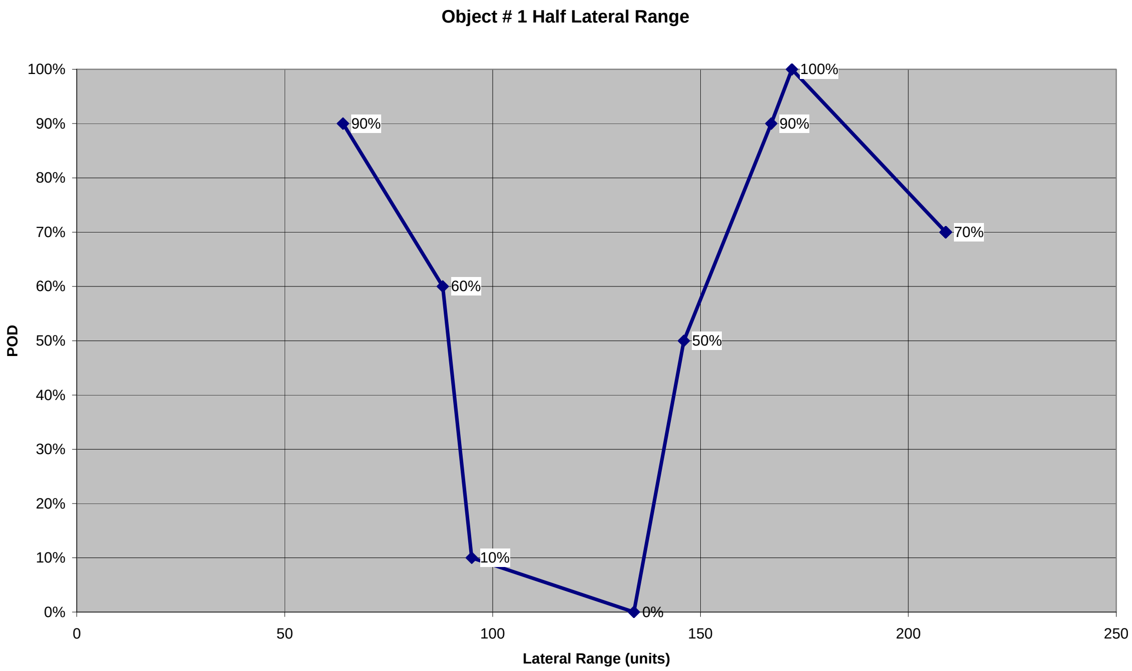

Figure 32 Lateral range curve of night experiment

Using the cone method often produces a smooth lateral curve and cross-over chart.

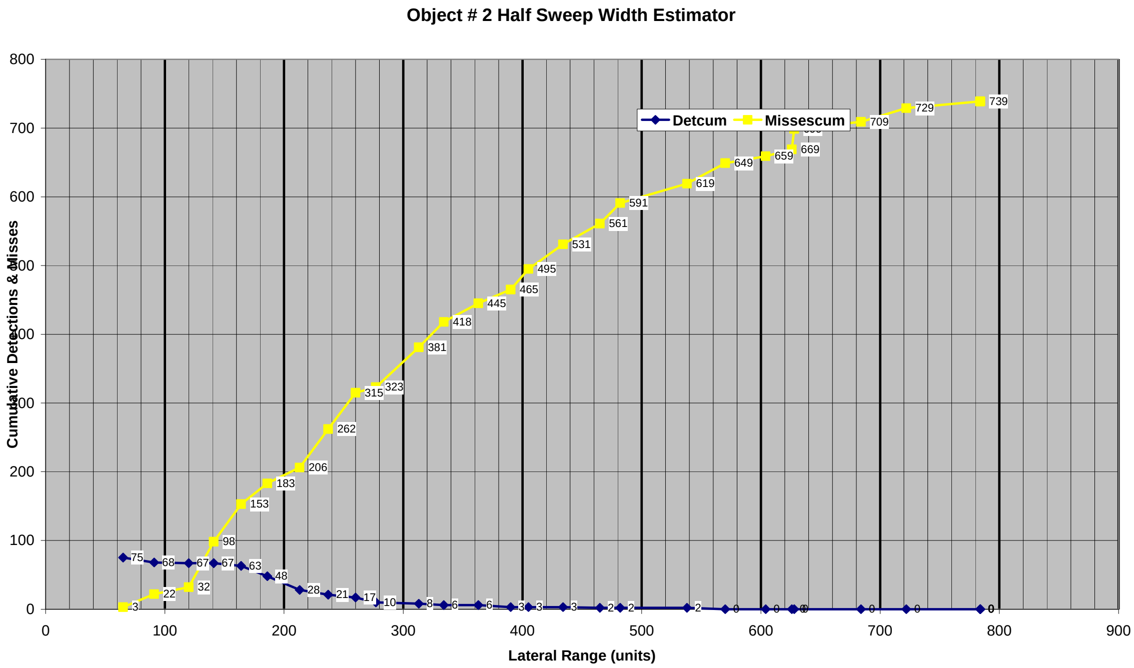

Figure 33 Cross-over graph using cone method for team detection

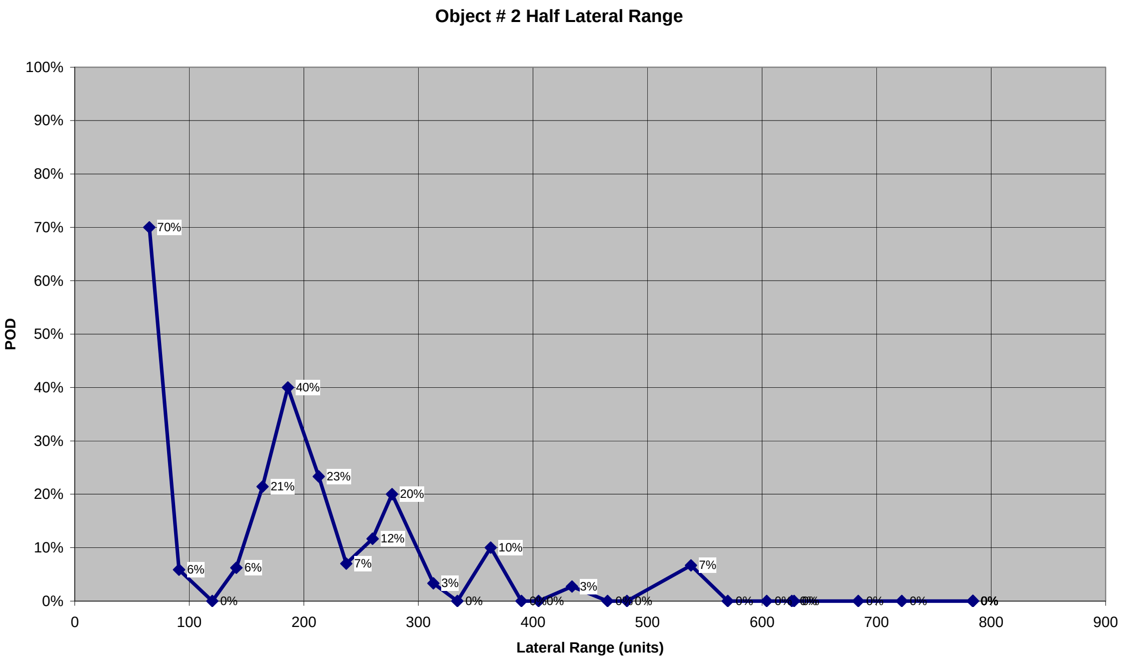

Figure 34 Lateral Range curve

This appears to be true. The detection index for the nighttime experiment (using the cone method) is 262 meters. Once again, this was less than the CPA method which resulted in a detection index of 306 meters. The difference between the two methods is 14%.

7.3.2 Subject Detection Experiment Results

The method use to score the subject's hearing the whistle blast detection range was similar to the day time experiment. However, during the night time experiment all seven of the subject's produced valid results. The team's detection index (CPA method) was 306 meters and the subject's detection index (also using CPA method) was 395 meters. Compared to the daytime subject detection index of 401 meters the results are almost identical.

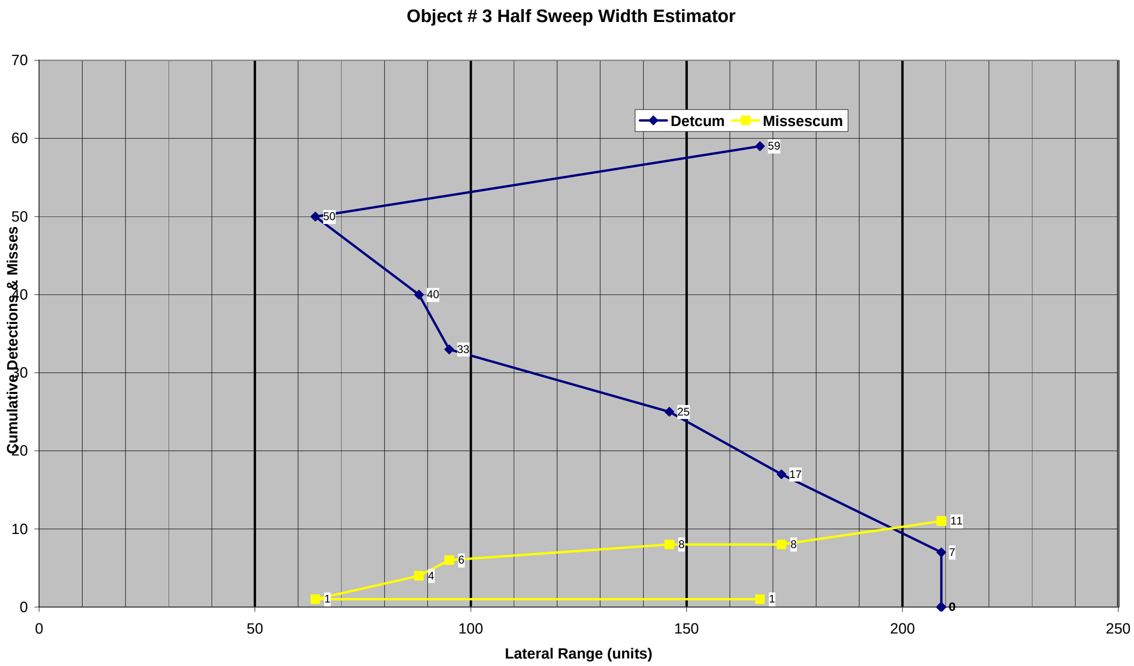

Figure 35 Cross over graph just achieves a cross over point

7.3.3 Night time Experiment – Subject Detection Light Experiment Results

In addition to the whistle blast, teams were using sound-light line tactics. Therefore, the subject also had the potential to detect the teams light. Subject's were instructed to only respond to whistle blast, but also to record when they detected light. The technique for scoring was the same method to use to determine which whistle blast matched a particular team. The detection index for subject's detecting light was 277 meters.

Location #	LR	Count	Detections	Misses	% Detected
D	64	10	9	1	90%
A	88	10		10	0%
G	95	10	4	6	40%
T	146	10	7	3	70%
E	167	5	1	4	20%
F	172	10	2	8	20%
Q	209	10	9	1	90%
Check Sums		65	32	33	
Effective Sweep Width			**277**	Meters	

Figure 36 Detection index for a subject detecting a search teams light source

The cross-over graph had a clear cross-over point. Which was a far better indicator than the lateral range graph.

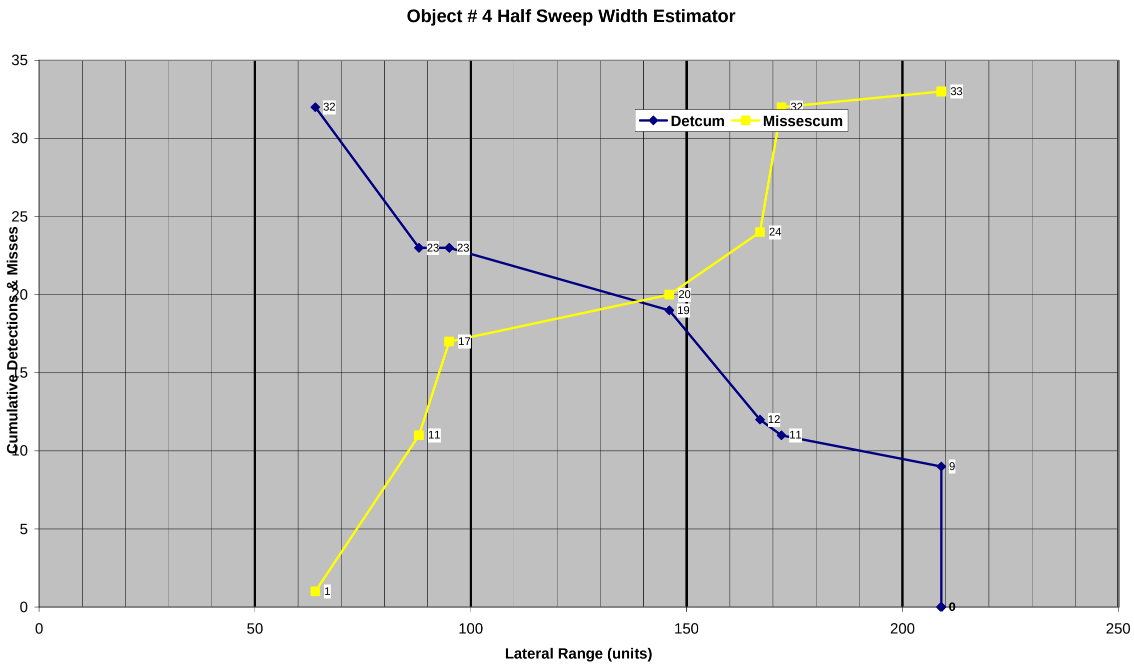

Figure 37 Cross over graph for light detection

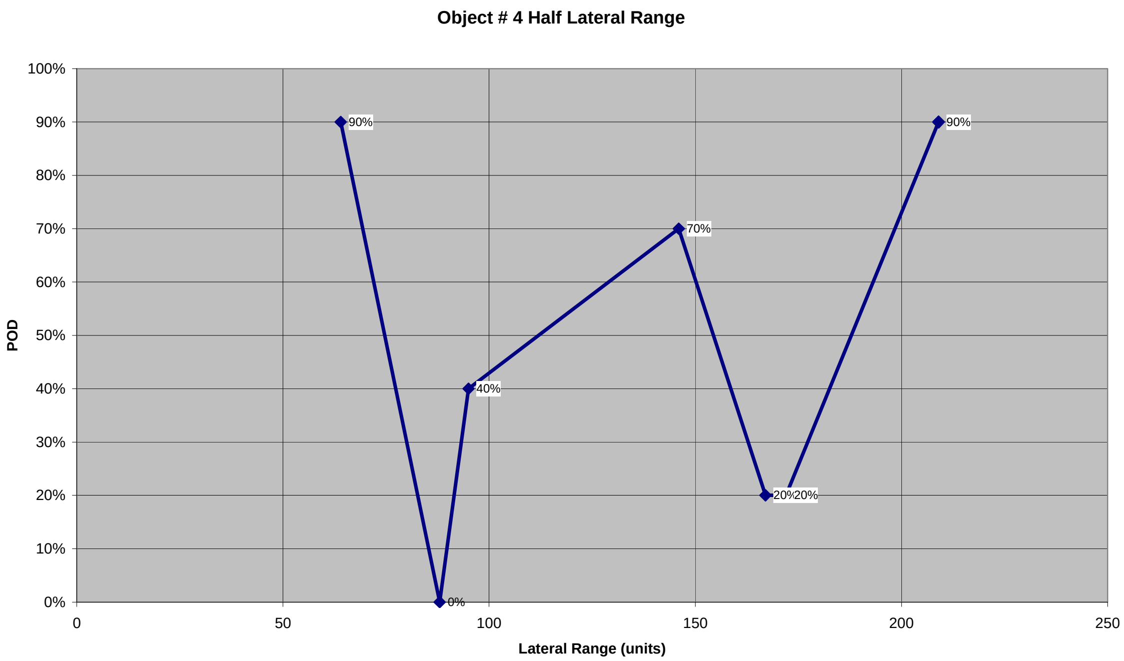

Figure 38 Lateral range curve for light detection

7.3.4 Night time Experiment – Subject Detection Overall Experiment Results

The sound-light line technique takes advantage of an alert responsive subject who may detect and respond to either sound or light. Their final analysis scores a detection if the subject either heard a whistle blast or saw light. While, the detection index for light (277 meters) was less than the detection index for hearing a whistle (395 meters), adding both together increased the overall detection rate to 460 meters. Therefore, some subjects heard whistles and did not see light, some saw light and did not hear a whistle, and some detected both signals. In this analysis any signal detected resulted in a detection. As before, only the closest point of approach (CPA) method was used.

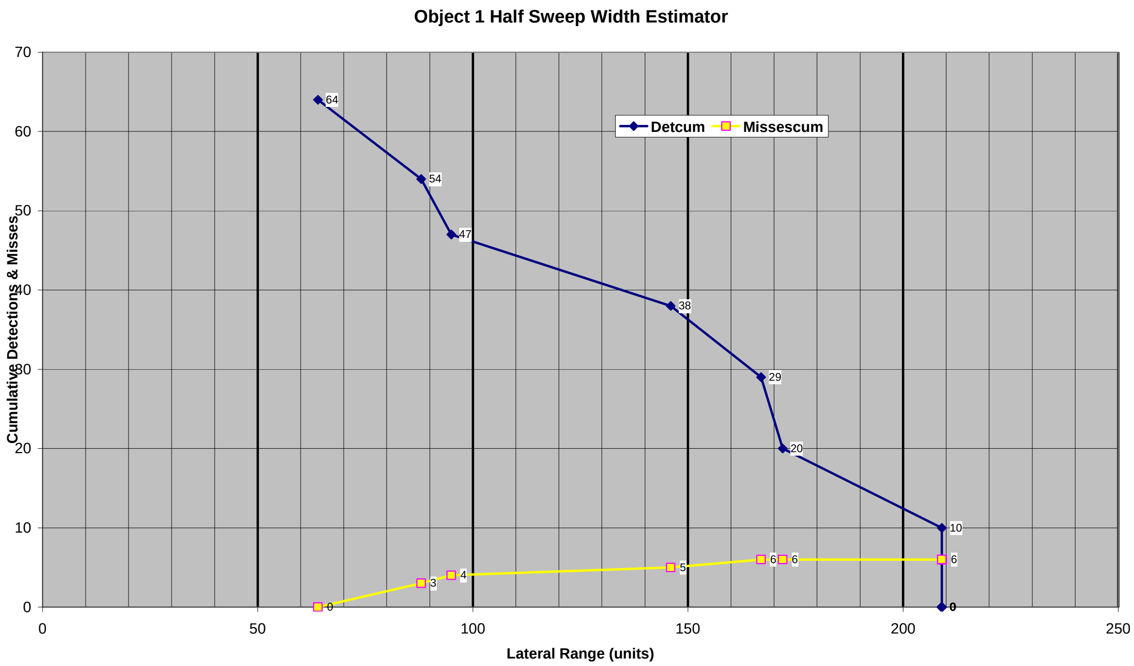

Figure 39 Cross-over fails to occur for overall. Subjects need to be placed further out.

A cross-over point did not occur. Therefore, the program defaults to the furthest lateral range, which was 209 and then doubles that value to give a detection index of 418 meters. In reality, the detection range is greater. One method of estimating the detection index involves simply extending the current trend line. This would give a half effective sweep width of 230 meters or a detection index of 460 meters. Clearly additional experiments are required to obtain a better figure.

7.4 Predicted versus actual detections.

As part of the debriefing process, each searcher was asked to give what percentage of the potential targets did they detect? This is similar to a typical debriefing question asked on many searchers in order to obtain a "POD" value. Since the number of search objects were fixed and known, it is possible to determine how accurate the searchers were with their predicted POD versus the actual POD.

Parameter	Average Predicted	Range Predicted	Actual % Detected	Offset
Sound (Day)	29%	0-90%	33%	± 18%
Sound (Night)	38%	5-75%	59%	± 23%
Orange Glove	84%	60-100%	99%	± 21%
Gray Glove	68%	10-100%	53%	± 37%

7.5 Overall Summary Experiment Results

The table below provides an overall summary of both day and night experiments.

Detection Type	Method	Day Experiment	Night Experiment
Searchers detecting subject	CPA	332 m	306 m
Searchers detecting subject	Cone	276 m	262 m
Subject hearing whistle	CPA	401 m	395 m
Subject seeing light	CPA	NA	277 m
Subject detecting searchers	CPA	401 m	460 m

The table below provides a summary of the hearing impaired versus normal hearing experiment. The hearing impaired subject reported a hearing loss of 70%.

Detection Type	Method	Hearing Loss	Normal hearing (same site)	Normal hearing (overall)
Subject hearing whistle	Cone	66 m	186 m	276 m

The Probability of Detection (POD) for a glove on the actual track during daylight.

	Number	Detection Opportunities	POD%	POD%
Orange Glove	12	144	99%	99%
Gray Glove	11	132	57%	52%
White Glove	1	11	0%	

Part IV – Conclusions and Recommendations

8. Project Goal

The proposal to the SARINZ trust stated the aim of this research as follows:

The overall aim of the research is to develop the methodology and process for the conduction of experiments using sound and light to establish sweep width tables for these methods in New Zealand conditions.

The two experiments demonstrated that it is possible to determine sweep width (detection index) values for sound and light line and sound and light sweep tactics. This study represents a technology transfer of previous experiments for visual search in a land environment conducted by the US Coast Guard (Koester et al. 2004).

8.1 Project Objectives

The research also successfully met all four of the objectives set out in the original study proposal.

The specific outcomes:

1. *The design of "international best practice" experiments to undertake sweep width trials for visual, sound and light search*
2. *The development of*
    - *experiment overview and process (why)*
    - *set up instructions, processes and experiment guidelines (how, where, etc.)*
    - *list of equipment and data collection forms/templates (what)*
3. *Concept testing during development*
4. *One full-blown field test of the final experiment design which will produce some limited preliminary data.*

1. The design of "international best practice" experiments to undertake sweep width trials for visual, sound and light search.

The experimental methodology was built upon the solid foundation of previous visual experiments to determine land-based detection indexes. The design and methodology of the visual experiments were in turn based upon maritime experiments conducted by the US Coast Guard Research and Development center. Key concepts such as detection opportunities, scoring each detection and non-detection, closest point of approach, looking at and for correction factors, generating lateral range curves, and using the cross-over technique to generate the actual detection index value have all been previously validated.

The challenge of this research was to adapt the specifics of experimental design and analysis for the specifics of sound-light line and sweep. This required direct observation of the techniques being taught and conducted by actual practitioners in the appropriate environment. This was accomplished by conducting and attending field trials, refresher courses, and field demonstrations prior to establishing the methodology. In addition, extensive conversations were conducted with knowledgeable searchers, including and going beyond the SARINZ instructor pool. This allowed for the development of the specific methodology, the goal of objective two.

2. The development of
- *experiment overview and process (why)*
- *set up instructions, processes and experiment guidelines (how, where, etc.)*
- *list of equipment and data collection forms/templates (what)*

The methodology is documented in section 3. Following are highlights of changes from the visual methodology:

- **Marked cones every 100 meters versus a flagging system**. Since the markers needed to be identified at night and each team needed to stop at the cone, it was important to ensure the marker was easy to see and would not move. Traffic cones with highly reflective markers held in place by fiberglass fencing poles and marked with flagging tape met the requirements. The materials were easy to obtain, relatively inexpensive, and could be used for multiple purposes in SAR.
- **Modified Average Maximum Detection Range (AMDR) Method**. For visual experiments a total of 16 measurements are taken from eight different angles. From each angle a detection range and extinction range are determined. The extinction range was added to the original AMDR methodology after one experiment almost failed as a result of search objects not being placed far enough out on the lateral range. For auditory experiments only the extinction range was recorded. The method was to simply walk away from the search subject who was blowing a whistle and shouting at a fixed interval.
- **Placement of humans as search subjects**. The gold standard for any search experiment is to create a search object that most closely matches the actual type of subject that is the objective of the search. In almost all SAR efforts the main objective is to locate a missing person. The sound-light search tactic is dependent upon a cooperative, conscious search subject. In fact, the tactic represents a two-way search problem. The search team sends out a signal (sound or light). The subject must then detect the signal and make a decision to respond. The subject then sends a signal back (sound being the most common). Finally, the search team needs to detect the signal from the subject. Only by placing actual human subjects in the field could a two-way detection be assessed.
- **Used un-alerted subjects and searchers**. All previous experiments with sound/whistles used alerted searchers. In other words, searchers knew when to expect to hear the whistle. In the design of this experiment neither the subjects nor the searchers knew when a signal might be present. In the course of the experiment some subjects heard a whistle every three to five minutes, while

others never to seldom heard whistles. As well, some teams covered the entire course without hearing a reply, while others heard only a few replies. Considerable thought and effort went into the methodology to maintain this feature.

- **Clear differentiation between signals generated by searchers from those made by subjects**. In order to properly score detections and non-detections it was critical that it was always possible to determine whether a subject or a team generated the signal. With multiple subjects and search teams out on the track at the same time the potential for confusion was high. In fact, some search teams did record hearing the whistle blasts from other teams. Therefore a rather simple rule was created. Search teams would only generate whistle or light. Subjects would only respond with a shout. This protocol worked well.
- **Creation of Subject Detection Log**. Since the subjects were in fact trained SAR personnel, it was possible to record the subject detections. In fact, these proved to be different from the searcher detections.
- **Measuring wind speeds**. One of the most important correction factors for hearing in the wilderness is the wind speed. It may be second to actual hearing ability in the list of correction factors. Therefore, it was critical to understand the wind dynamics for each detection, from both the searcher's and subject's perspective. While it would have been possible in a controlled experimental setting to issue an anemometer to every subject and every team, this would be cost prohibitive and unlikely to reflect actual search reality. Even a single measurement taken from a fixed location with an anemometer would not reflect the variability in the field. It was then decided to utilize the Beaufort scale. The Beaufort scale has been modified to estimate ranges of wind speeds using visual clues readily available on land. The searchers recorded the Beaufort number for each cone location (whistle blast). Meanwhile, the subject recorded the number whenever he heard a whistle blast. The analysis of wind data is beyond the scope of this report.
- **Identify hearing loss as a correction factor**. As the differences in detection index between "normal" hearing and known hearing loss of 70% demonstrate, hearing loss is a major correction factor. In order to fully control for differences in hearing loss between searchers and search subjects, the original concept was to test each subject's and searcher's hearing. This will remain an important component of future experiments. It did not work well for reasons which will be described under key recommendations at the end of this report.
- **Data collection forms**. Many of the forms used in visual experiments were not suitable for use in a sound/light experiment. Therefore, several new forms were created for these experiments.

3. Concept testing during development.

Throughout the development of the revised methodology several small tests were performed. This often consisted of thought experiments to work thorough the future experiment and determine problems that might arise. Hardware and software used for the experiments were tested. On the actual day of the experiment no major problems arose.

Figure 40 Photo of location AMDR performed

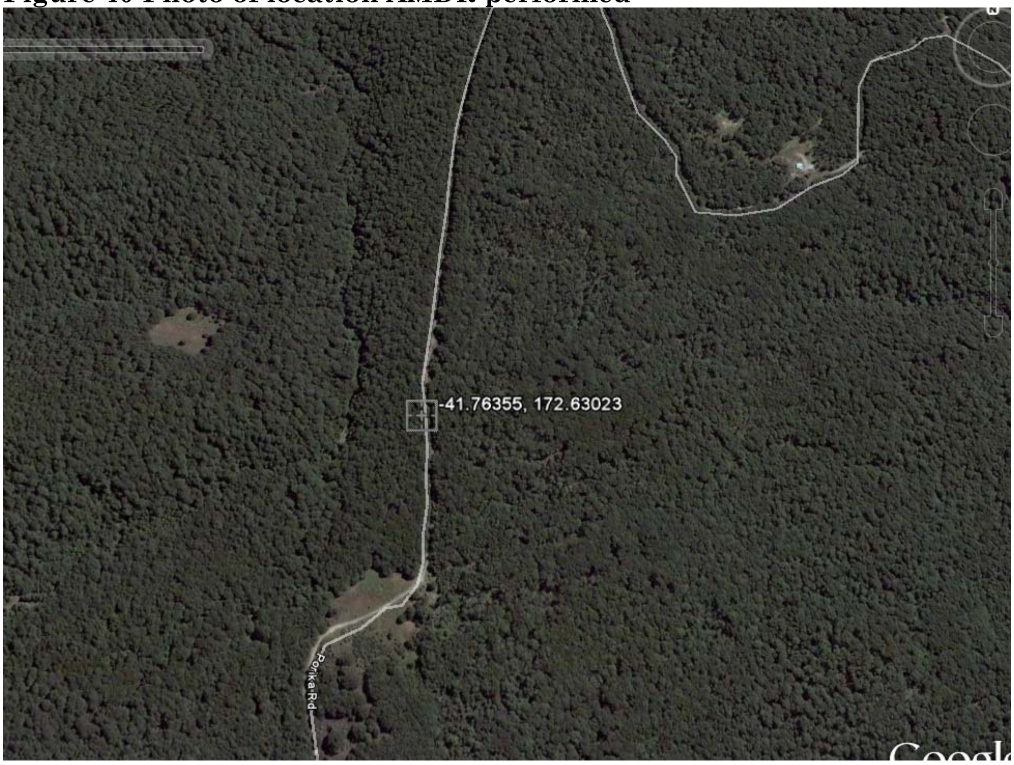

Figure 41 Overview of AMDR location

9. Key Findings

The pilot experiment designed to test the methodology resulted in several key findings.

- **It is possible to obtain a detection index for sound tactics**. The experiment clearly showed it was possible to obtain a detection index for sound and/or light line tactics. Furthermore, the fact that the closest point of approach method (with 80 detection opportunities) and the cone method (with 472 detection opportunities) provided similar results indicates smaller experiments can be conducted. This is further bolstered by the fact that the day and night experiments resulted in a team detection index of 332 and 306 meters respectively, a difference of only 8%. The difference for the subjects hearing the whistle was only 1%.
- **First reported detection index for light tactics**. This experiment was the first reported experiment of detection of light in a realistic search environment. While the current theoretical limit for detecting light is a distance of 7.5 billion light years away (Immler et al., 2008), a more practical distance needs to be based upon handheld torches versus gamma ray bursts. Since the experiments took place in a forested area in mountainous terrain, it is expected that distances would be small. In fact, the detection index for a subject detecting the light was 277 meters. It is interesting to note that the detection index for light appeared to be independent of the detection index for sound. Therefore, the detection index for a subject detecting a team increased to 460 meters when both sound and light were considered. Depending upon conditions, it is expected that the detection index for light would be large.
- **The detection index generated for sound is comparable to previous studies**. While no previous studies generated a detection index for unalerted searchers, the maximum ranges do provide some insight. A previous test of several different whistle types conducted in New Zealand (Were, 2006) showed for the loudest whistle the maximum range was between 300 to 500 meters depending upon the conditions. This experiment generated a detection index of 400 meters for a subject detecting a whistle. After taking into account differences between alerted and unalerted searchers, different whistle types, and the left/right nature of a detection index, the results are somewhat comparable. The first classic sound study was conducted in Canada (Coldwell, 1989). This study was conducted under more search-like conditions (although some of the staff that set up the course were also used in testing). The study results were reported as a lateral range curve. Using the cross-over technique found in IDEA it is possible to convert a lateral range curve into a detection index. This gives a detection index of 313 meters. It is worth noting that the Canadian experiments were conducted in a Pacific West Coast coniferous forest. Also carried out in the Pacific West Coast coniferous forest was a recent study (Manson, 2009). This study reported both maximum and minimum attention getting ranges. The minimum attention getting range was a subjective measurement determined by the searcher. Depending upon the whistle type and season this ranged from 200 to 400 meters. This study used alerted searchers.
- **It will be critical to identify key correction factors.** The wind played a key role in both the subject's and searcher's ability to detect the sound. Another key finding was the importance of subject's hearing. In the one team where both members recorded their individual results, one member heard nothing and the second made all the detections. It is clear that there are trained, skilled searchers being deployed on actual missions who may have significant hearing issues. The

subject with a 70% hearing loss had a correction factor of 0.35 or a detection index that was 65% reduced. With additional experiments it will be interesting to see if a linear relationship exists. Another key correction factor is terrain. In fact, terrain, along with vegetation, can be so variable that experiments may need to start with a base detection index based upon the terrain type. Season is also expected to be a major factor.

- **The cone method will allow quantification of correction factors.** Using the cone method (measuring the lateral range from each cone to the subject) allows a detection index to be generated for each subject based upon hundreds of detection opportunities. It will then be possible to determine the percentage change that each correction factor produces for each subject. The percentage change can then be averaged for each subject. This will not only generate an average but allow for more advanced statistical analysis since it will be based upon more data.
- **Experiments can be conducted for relatively low cost.** After fixed costs of measuring wheels, dBA sound meter, handheld weather station, cones, fiberglass poles, reflective tape, and hearing test equipment are obtained few other costs remain. Gloves, paint, tent pegs, and flagging tape will be required for each experiment. Also each experiment would require printing forms and maps on waterproof paper. The greatest cost remains personnel and travel expenses. In most cases the bulk of personnel and travel can be borne by volunteer searches. However, in this case some additional money should be allocated for food and perhaps batteries. Logistical support such as command buses, power, radios (at least one for each subject), GPS units (for each subject) will also need to be provided.

10. Key Recommendations

While the pilot experiment did prove to be a success and valuable data was generated, the true value of the study was a technology transfer from previous US Coast Guard efforts to the SARINZ trust. It clearly shows that the methodology previously adapted for ground visual experiments could be adapted to sound–light experiments. The ability to conduct sound–light experiments has been successfully transferred. The ability to enter the data, analyze the results, and draw scientific conclusions may still require some assistance. However, like most pilot experiments several important factors have been identified that could improve future experiments.

10.1 Additional Experiments

- **Conduct additional experiments in different terrain.** The pilot experiments represent a ridge based experiment. This is a common location for tracks and roads in a mountainous environment. A total of four different types of terrain exist where tracks and roads are found. The other three types of terrain will need to have experiments at some point before a meaningful table can be built for detection indexes. The common locations for tracks and roads include:
  - Ridge top
  - Valley bottom
  - Side of mountain
  - Flat terrain
- **Conduct additional experiments in different types of foliage.** The pilot experiment was conducted during the winter in a beech forest. Some parts of New Zealand have much more dense forest and other parts more open. The forest should be characterized by both the diameter of trees and the overall density. Density of the forest can be estimated by visual distance at eye-level. At this point it is difficult to determine if type of foliage will result in a completely different table of detection index or if it may be simplified down to a simple correction factor. As an interim step before full-blown experiments are conducted it might be possible to conduct some simple studies with a small experiment team. A theoretical (with numbers completely made up!) correction factor table could look like the following:

Foliage	Description	Correction Factor
None	No foliage over eye-level	1.1
Sparse	Visibility limited to 100 meters or less at eye level	1.0
Medium	Visibility limited to 50 meters or less at eye level	0.75
Thick	Visibility limited to 10 meters or less at eye level	0.4

- **Conduct additional experiments to determine environmental correction factors.** The two most critical correction factors may be background noises such as wind and rain. In order to make a sound detection either the search subject or searcher, the physical energy of the signal must vibrate the ear drum, and then the brain needs to recognize and detect the signal as something of interest. This is often referred to as the Signal to Noise Ratio (SNR). If the signal is lost in the noise it will not be detected. Much like stars are shining during the day, but the noise of the blue sky makes it impossible to detect any stars other than our local sun. While the threshold of hearing is at 0 dBA for someone with perfect hearing in a perfectly quiet environment, this typically does not describe the types of environments found in the outdoors. The following table gives some of the types of background noise that may be typically found in the outdoors.

Environment	Loudness (dbA)
Normal quiet coniferous forest	33
Normal quiet deciduous forest	
Deciduous forest with cicadas	60
Mountain creek/river, moderate flow at 10 meters	66
Light rain in deciduous forest	52
Light rain on nylon jacket hood	57
Light rain coniferous forest	63
Heavy rain	68
Wind, open 10 kmph	65
Wind, open 32 kmph	80
Wind, open 40 kmph	90
Wind, open 70 kmph	105

Clearly wind and rain are important correction factors. Rain has two important influences on the ability to detect sound: first the actual increase in background sound it creates; and second, the muffling effect of wearing a hood. The current methodology already measures wind speed at each cone and at each subject by using the Beaufort scale. This proved to be successful and should continue. The following chart was carried by all searchers.

Beaufort Wind Scale

Beaufort Number	Wind Speed km/hr	mph	knots	Description	Illustration	Effects Land
0	<1	<1	<1	Calm		Still, calm air, smoke will rise vertically.
1	1-5	1-3	1-3	Light Air		Rising smoke drifts, wind vane is inactive.
2	6-11	4-7	4-6	Light Breeze		Leaves rustle, can feel wind on your face, wind vanes begin to move.
3	12-19	8-12	7-10	Gentle Breeze		Leaves and small twigs move, light weight flags extend.
4	20-28	13-18	11-16	Moderate Breeze		Small branches move, raises dust, leaves and paper.
5	29-38	19-24	17-21	Fresh Breeze		Small trees sway.
6	39-49	25-31	22-27	Strong Breeze		Large tree branches move, telephone wires begin to "whistle", umbrellas are difficult to keep under control.
7	50-61	32-38	28-33	Moderate or Near Gale		Large trees sway, becoming difficult to walk.
8	62-74	39-46	34-40	Gale or Fresh Gale		Twigs and small branches are broken from trees, walking is difficult.
9	75-88	47-54	41-47	Strong Gale		Slight damage occurs to buildings, shingles are blown off of roofs.
10	89-102	55-63	48-55	Whole Gale or Storm		Trees are broken or uprooted, building damage is considerable.
11	103-117	64-72	56-63	Violent Storm		Extensive widespread damage.
12	118+	73+	64+	Hurricane		Extreme destruction, devastation.

In order to determine correction factors, experiments should be carried out in the same location under different conditions. It is also possible to conduct analysis if the conditions change over the course of a single experiment. While wind conditions are currently captured for each cone, factors such as rain are not. Therefore, the searcher detection log should be modified to capture this key correction factor.

To determine correction factors from a single experiment the condition of interest must have changed during the experiment. Search teams could then be split into groups for each subject based upon each condition (wind speed, rain, etc). Then by using the cone method it would be possible to determine the detection index for each subject under each condition. This is accomplished since the cone method allows the determination of detection index based upon a single teams pass (as long as at least one detection was made). With multiple teams a more reliable detection index for each condition can be determined. The percentage change of the different conditions can be determined for each condition per subject. Then all of the percentage changes can be statistically combined for all of the subjects to determine an overall correction factor for the condition of interest. The greater the number of subjects and experiments, the more reliable the correction factor becomes. Below is what a theoretical correction factor for background noise might look like.

Condition Factor	Correction Factor
Normal quiet coniferous forest	1.0
Normal quiet deciduous forest	1.0
Deciduous forest with cicadas (day)	0.5
Mountain creek/river, moderate flow at 10 meters	0.5
Light rain in deciduous forest	0.5
Light rain coniferous forest	0.5
Heavy rain	0.4
Wind, open 10 kmph	0.9
Wind, open 32 kmph	0.5
Wind, open 40 kmph	0.4
Wind, open 70 kmph	0.2

The two pilot experiments contained enough wind data that some analysis of a wind correction factor is possible, but the effort that would be needed is beyond the scope of this contract.

- Determine the correction factor for hearing loss. Hearing loss is obviously a significant correction factor. The subject with a 70% hearing loss had a correction factor of 0.35. One searcher with hearing loss (amount unknown) did not detect any subjects. A significant amount of effort went into looking at different ways of screening hearing loss that could be used in a field environment. A low cost screening tool (Home Audiometer 2.0) that could be delivered via a laptop computer was obtained and tested using enhanced quality headphones. Calibration required someone with normal hearing and did not allow for calibration of testing equipment through electronic means. On the day of the experiment, the only "quiet" location that allowed for a face to face sitting out of the wind was the command bus. However, the generator in the bus caused a significant change in the hearing profile at the lower frequencies. In addition, the test results did not result in a simple hearing loss percentage. The frequency range that needs to be tested is from 150 Hz (lower limit of male voice) to 3000 Hz (upper limit of female voice). However, special emphasis may need to be paid to 2000 – 12,000 Hz since this is where several whistles used in SAR peak. Once a better field audiometer is determined it is recommended that ear buds be used as microphones. These can be run under high quality ear muffs that can reduce outside sound by 30 dB (NRR). Additional consultation with a hearing professional is encouraged to find the best combination of testing equipment and procedure. The actual screening test should be limited to no more than 5 minutes. The score should be reduced to a single number or value for later use in determining correction factors.