SARINZ
SEARCH AND RESCUE INSTITUTE
NEW ZEALAND
Helping others save lives

SARINZ POD Experiments

The Development of a Detection Index for Sound and Light

Interim Report 2010

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 daytime 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. 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.

Key Project Metric

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 LLC

Assistant Researchers: Ross Gordon, Tony Wells

Support Organisations: SARINZ Ltd, Tasman Land Search and Rescue, Tasman Police, Canterbury Land Search and Rescue, Dunedin Land Search and Rescue

Specific Objectives:

• The design of an "international best practice" experiment	Achieved
• 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
• Concept testing during development	Achieved
• A full field-test of the experiment design & development of preliminary data	Achieved

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 centre. 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)*

Some changes from the visual methodology are:

- **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.
- **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.
- **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.

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.

4. One full-blown field test of the final experiment design which will produce some limited preliminary data.

The ultimate success of the methodology is evidenced by the two successful experiments. The day experiment tested sound and was mixed with a visual experiment for gloves. The night experiment tested sound and light. While future experiments will have slight modifications to the methodology, the results obtained are valid.

Search Subjects

A major difference between this experiment and all other experiments that involved sound detection was the use of actual human subjects. The fundamental issue with sound and light detection is the two-way nature of the detection. It requires to cooperating elements that wish to find each other. The searcher desires to detect the search subject and the search subject wishes to be found. The search team sends out an initial signal (sound and/or light) and the subject must first detect the signal; recognize it for what it represents, and then respond in some fashion. Based upon conversations with SARINZ instructors it was determined the most common signal generated by search teams is a whistle blast. Then depending upon the subject type and scenario teams will sometimes augment the whistle blast by shouting the subject's name. It was then stated that approximately 90% of the time the response is a shout from the subject. Therefore, from an experimental point of view the ideal "search object" would be one that could recognize a whistle blast and then respond with a human voice. It was felt a human voice would be important since human sensory and processing systems are ideally suited to recognize a human voice across many different frequencies and hidden in background noise. It was also felt the reply voice should be a short discrete signal and not a constant noise to aid in the detection of the voice. Therefore, it was felt that by using actual humans as the search subjects a detection index which actually reflects reality most closely would be obtained.

The use of human subjects does have some negative features. It requires that more participants must be recruited for each experiment. It also requires that the subjects are better trained and equipped since they must spend long periods without movement in the woods. Some basic navigation skills are required to reach the designated location for each subject. Another complication was the additional time required to place actual subjects. Unlike the visual experiment with manikins, human subjects could not be placed the day before the experiment. Placing the subjects delayed the start of the experiment by almost an hour in both experiments. However, much of this delay could have been avoided with better planning. Another important consideration with placing actual human subjects was increased safety risks. One subject did become slightly "lost" in attempting to move back to the road. Ensuring everyone has a compass and sets the bearing into the woods and knows how to backtrack out of the woods must be a standard part of the subject briefing. Regular safety and welfare checks (at least every hour) should be performed. The experiment did come close to or reach the limits of safety in regards to the wind in some of the locations. Appointing a safety officer is important during an experiment just as it is at a regular search incident. Using human subjects also introduces greater variability due to differences in hearing, voice characteristics, voice loudness, and ability to enhance a shout. However, in the real world, subjects will have a vast and unknown set of shouting characteristics.

More importantly, in the real world subjects don't know when they will hear a shout. The experiment methodology ensured that search subjects were un-alerted. In other words, they did not know when a team would whistle. In return, search teams were also un-alerted, since they had no idea when they would hear a reply. Future experiments should continue to use actual subjects. One potential change might be to use real subjects, but when they hear a signal they play a portable speaker with a prerecorded message that is set at a fixed and measured loudness.

Location of AMDR for field trial

Background

Searching, 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 organisation familiar to those engaged in search and rescue. Much progress has been made in the organisation 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. 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. This 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.

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.**
- 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.

Previous Sound Experiments

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.

In 2006, Cayla Were et al. undertook whistle trials to determine the effective range of different whistles utilised by SAR practitioners in New Zealand. These experiments were undertaken in North Island bush conditions on Mount Pirongia and in the Kaimai Ranges. The maximum effective distance that each whistle could be heard was recorded. This process was repeated at five additional sites and an average distanced calculated. Like previous experiments, these trials involved priming the detector to listen for the whistle. It is worth noting that the average effective distance from the 2006 Were trials are directly comparable to the AMDR tests in the Nelson Lakes Beech forest undertaken for the 2010 SARINZ Trust POD experiments **for an alerted or primed subject**.

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.

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 outcomes described in this report are intended for SAR managers to establish detection index values for 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. 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:

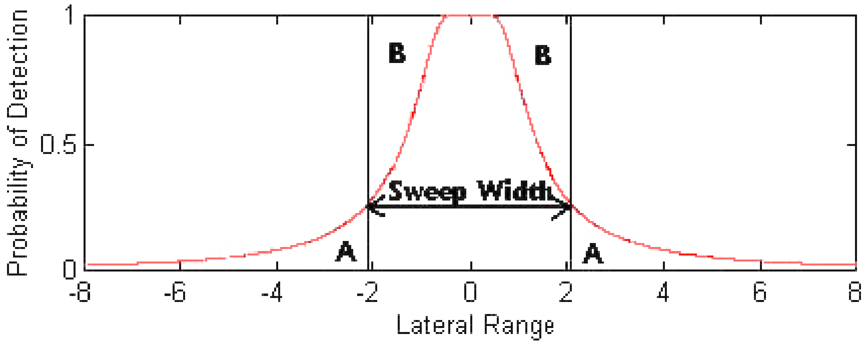
- The "detection index" for the combination of search object, search environment, and sensor (e.g., auditory search from the ground) present in a given search situation,
- The amount of effort expended in searching the area, and
- The size of the area where the effort was expended.

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.

Detection Index (Sweep width)

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) equals the number that are detected at greater distances from the searcher's track (areas A below the curve), then one has found the effective sweep width.



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.

"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 travelled 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,

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

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.

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 cancelled 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. The graph (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 travelling 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.

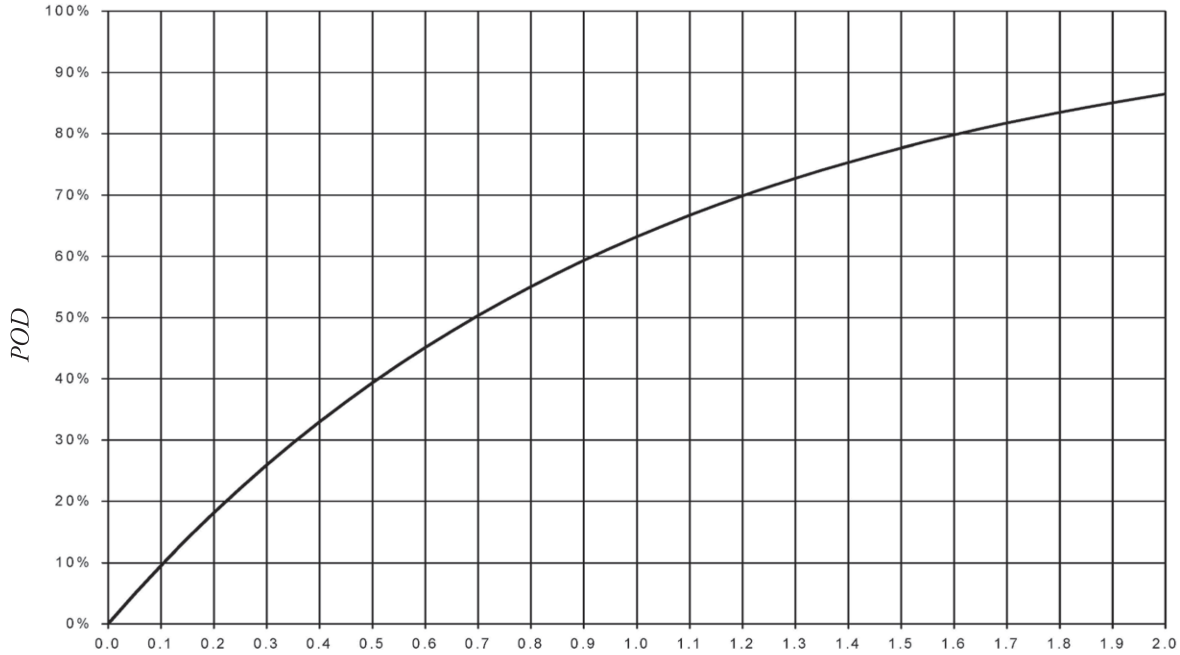
Since terrain and vegetation often prevent ground searchers from following a mathematically precise pattern of parallel tracks, and since ground searchers frequently alter their tracks to investigate possible sightings, look behind major obstructions, etc., the exponential detection function, as the curve 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.

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 (PODcum) 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.



POD versus Coverage (Koopman, 1946)

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

Mike Fitzsimmons helps mark the trial route

Trial Location

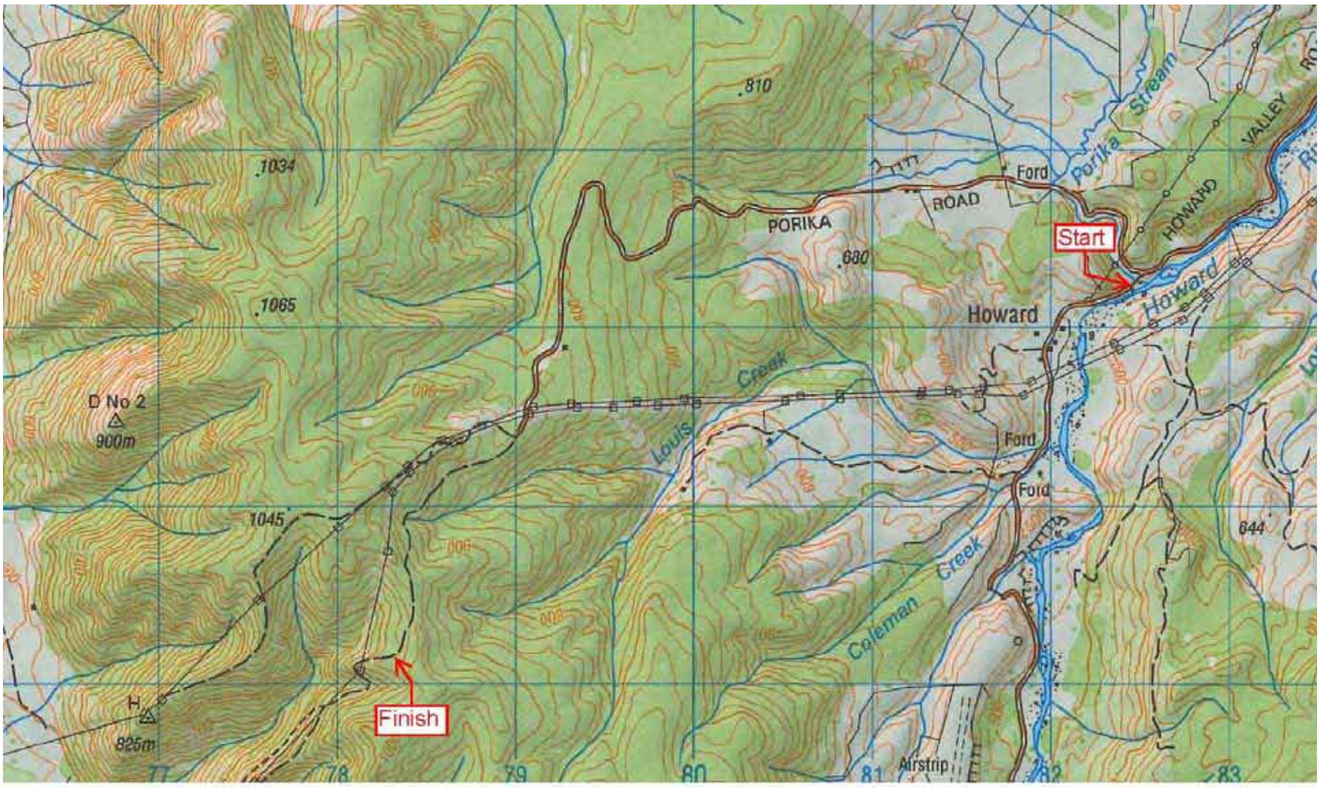
Proof of concept testing – Nelson Lakes St. Arnaud New Zealand

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.

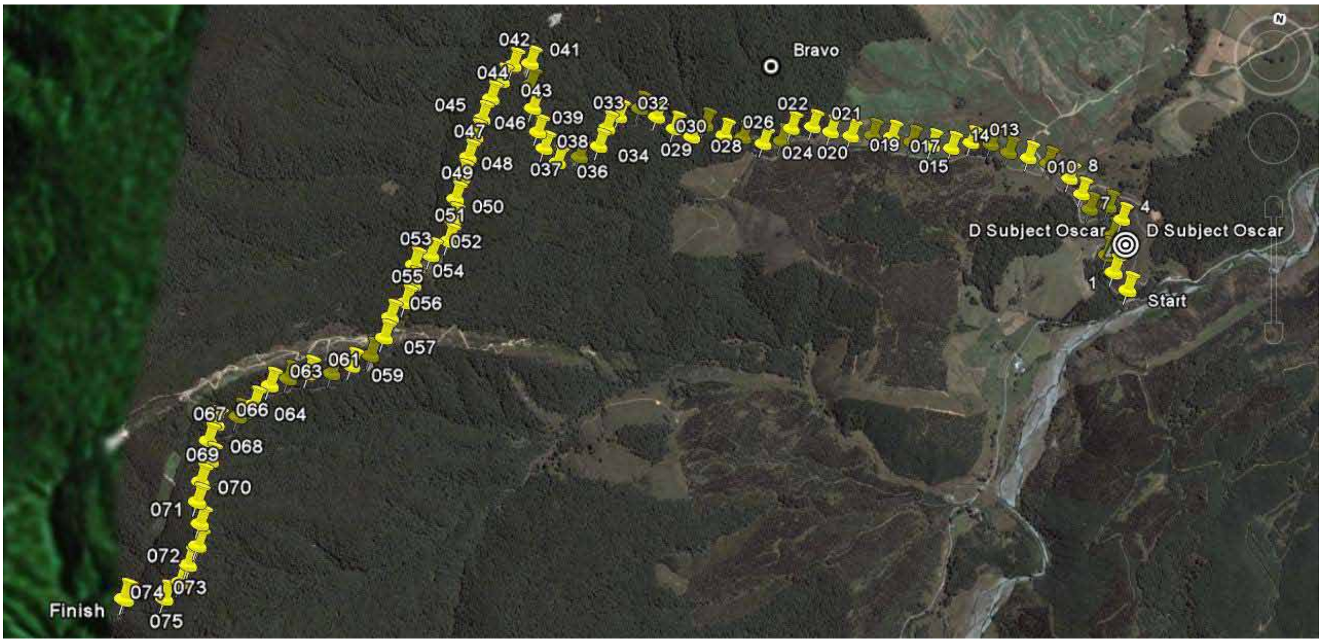
During the last Ice Age massive glaciers gouged out troughs in the mountainous headwaters of the Buller River. Today these troughs are filled by Lakes Rotoiti and Rotoroa, which give the Park its name. They are the largest lakes in the area.

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'.



Topographic map of search track



Google Earth top down view

Course Selection Discussion

The general location was chosen due to the willingness and dedication of Russell "Sherp" Tucker, Assistant Police SAR Coordinator of the Tasman 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, to be lightly travelled or be able to control traffic
- Able to find a staging area for parking in close proximity to start
- Ideal if trail is 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.

Participant Recruitment

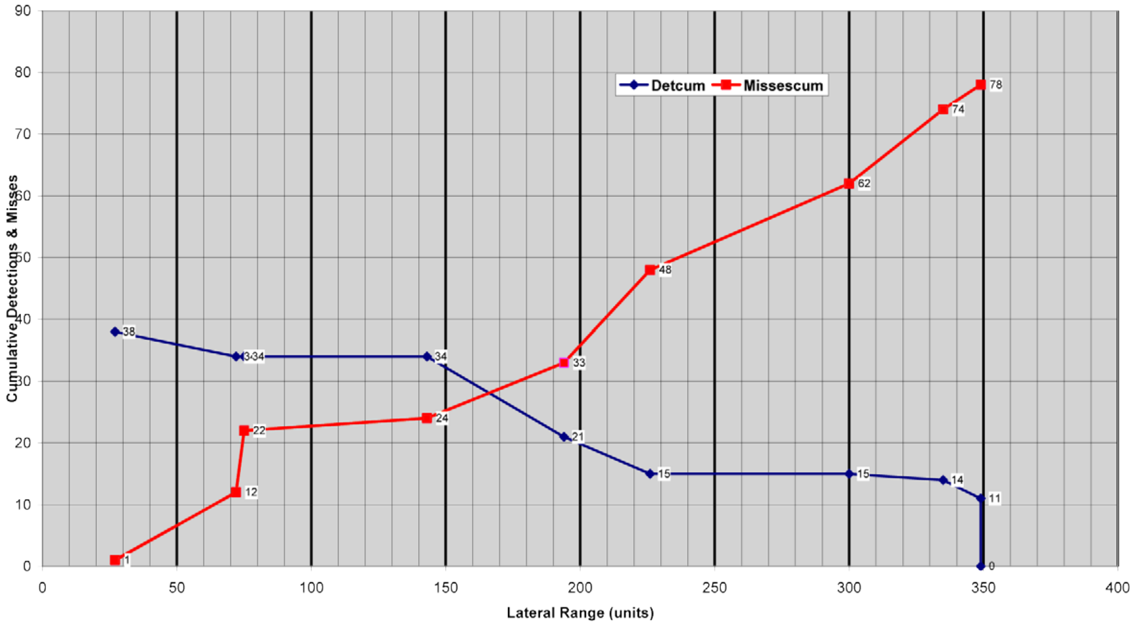
The Nelson Lakes experiment was a dedicated experiment event held at Nelson Lakes. Participants were recruited mostly by Sherp Tucker with some additional participants recruited from the Canterbury district by Tony Wells. All searchers belonged to a search team or played an active role in search and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

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 nighttime experiment involved a sound light line tactic. 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.

Day Experiment – Team Detection 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. If the subject heard the whistle, the subject responded by shouting "Hey, its Bravo." If the search 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.



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.

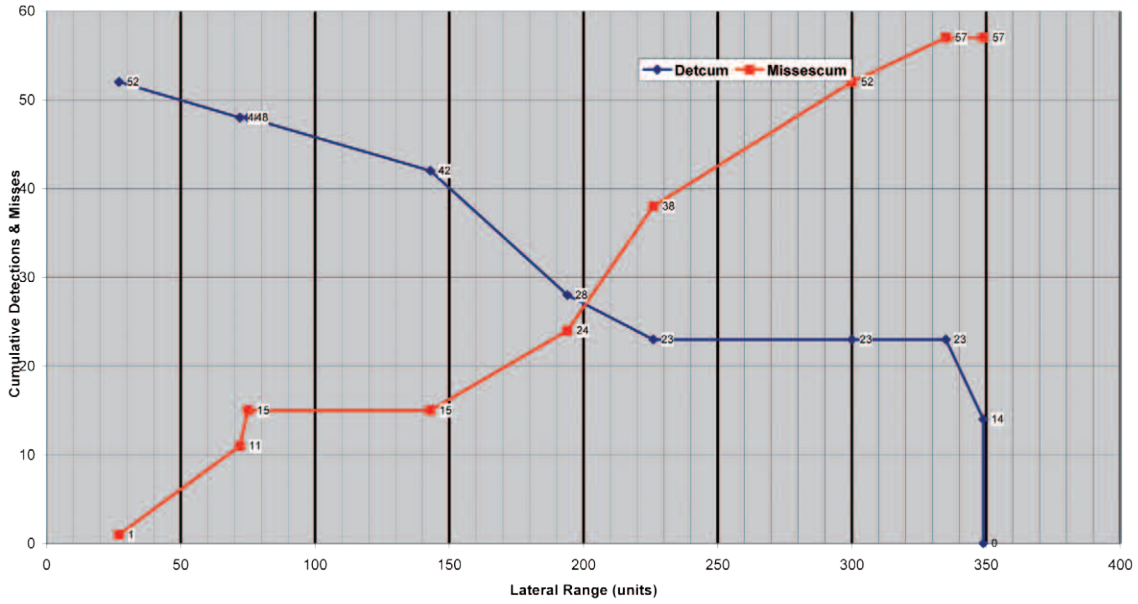
Day Experiment – Subject Detection Results

Since auditory search is a two-way search problem, it is also useful to determine the Subjects detection index of hearing the whistle blast. It was impossible to determine where the team was located during the whistle blast from the subject's perspective. 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 team's 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.

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 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
CharlieVI	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				

Subject detecting teams data.



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.

Day 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 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%	

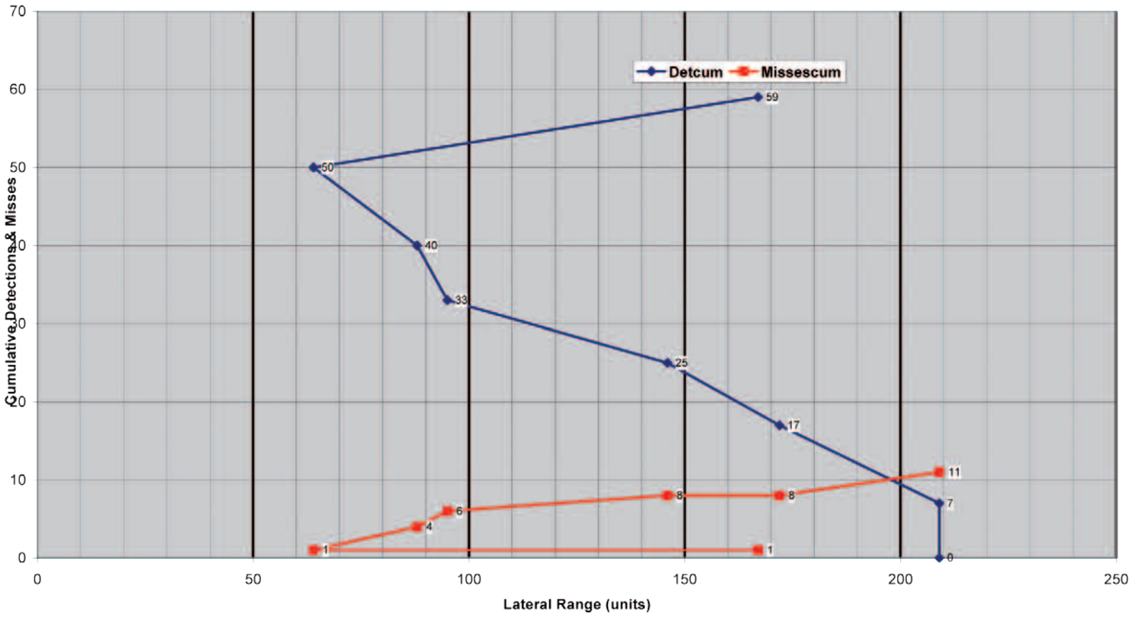
Detection rates for clues on track

The last team (team 14) consisted of one person 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.

Night Experiment – Subject Detection Sound Results

The method use to score the subject's hearing the whistle blast detection range was similar to the daytime experiment. However, during the nighttime experiment all seven of the subject's produced valid results. The team's detection index was 306 meters and the subject's detection index was 395 meters. This is almost identical to the daytime subject detection index of 401 meters. Once again subjects heard searchers from a greater distance than searchers heard subjects respond.



Cross over graph just achieves a cross over point

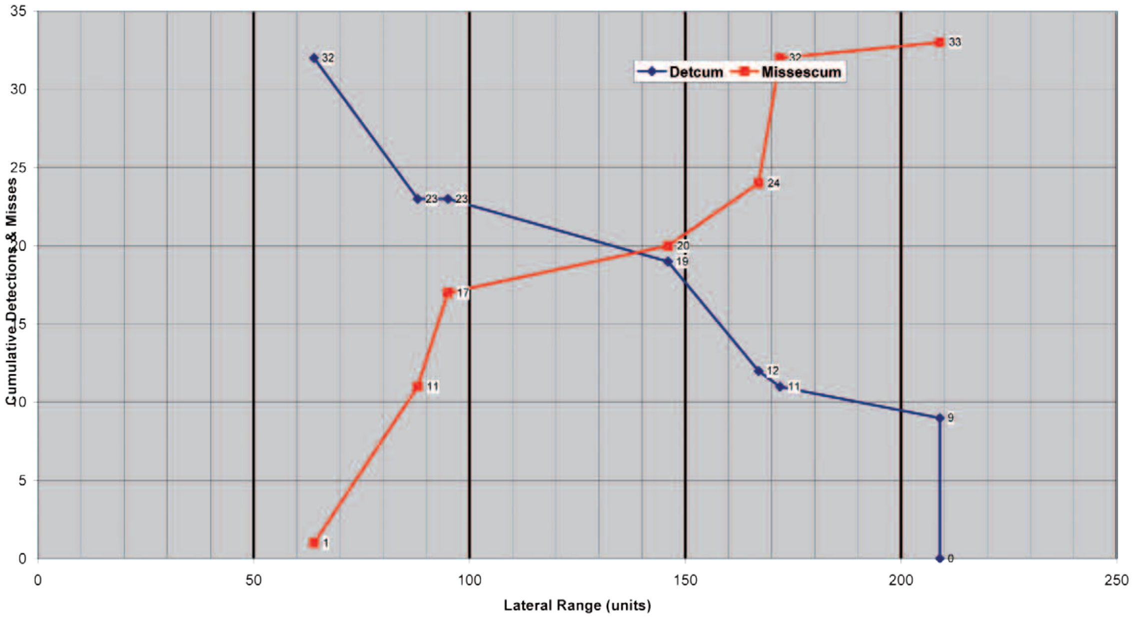
Night Experiment – Subject Detection Light Results

In addition to the whistle blast, teams were using light tactics. Therefore, the subject also had the potential to detect the teams light. Subject's were instructed to only respond to a whistle blast, but to record when they detected light. The detection index for subject's detecting light was only 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			66 Meters		

Detection index for a subject detecting a search teams light source

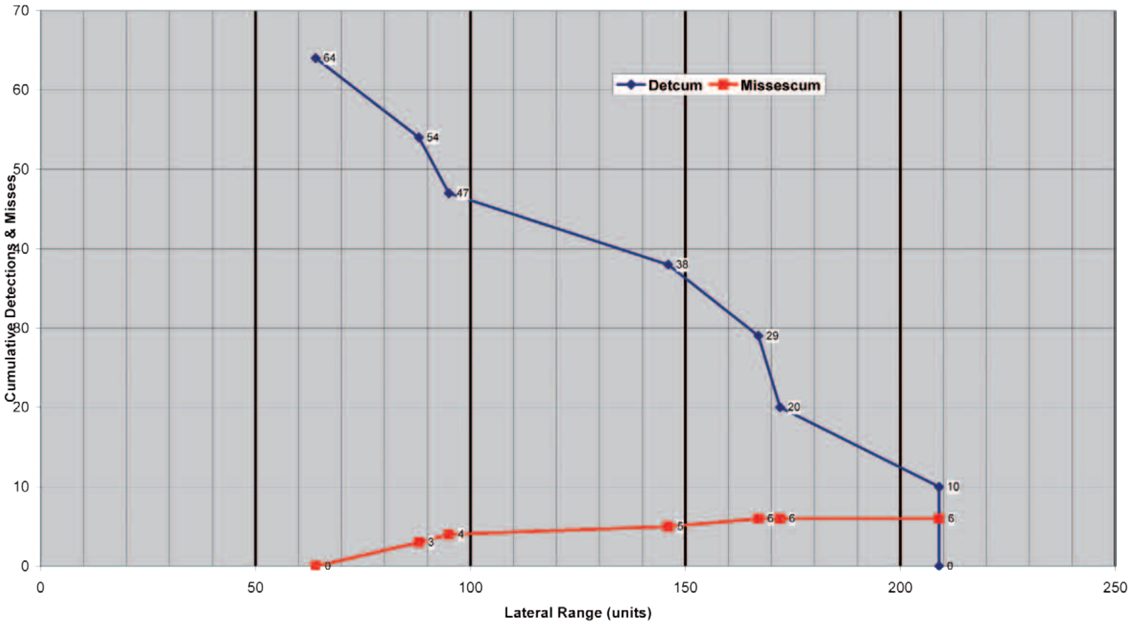
The cross-over graph had a clear cross-over point. Which was a far better indicator than the lateral range graph.



Cross over graph for light detection

Night Experiment – Subject Detection Overall 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.



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.

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%

Overall Summary Experiment Results

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

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

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%	

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 un-alerted 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 un-alerted searchers, different whistle types, and the left/right nature of a detection index, the results are somewhat comparable. The first classic sound study was conducted in Canada (Coldwell, 1989). This study was conducted under more search-like conditions (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.

While the 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.

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. 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

Moving Forward

The report completed by Robert Koester at the end of development and testing phase listed a number of recommendations. One of the key recommendations was to conduct additional trials in differing environments to build a more comprehensive data set. SARINZ is currently seeking funding to do exactly that. As with all experiments it is a case of more experiments equals more data, the more data the better the result. The conducting of further experiments is subject to ongoing funding. It is planned that trials at two additional locations will be conducted (the minimum recommended in the original report). One of these would be in flat bush covered terrain, with the other in a valley system. All other data as per the original trial would also be collected – wind strength, bush profile, whistle strength, etc. One daytime and one nighttime trial would be conducted at each location. The data collected from these trials, combined with the original trial data would provide sufficient information to be able to make some informed judgement statements about detection and POD in New Zealand bush conditions regarding the use of sound and light as a detection resource.

It is ultimately envisaged a more comprehensive set of tables would be developed so that search teams would not have to report POD via the current best guess method but rather report the spacing between team members and the correction factors (eg: foliage density, background noise, wind speed) from which a scientifically based POD could be established. Whilst there will always be a small amount of variability within the system, this POD will be much more accurate than current methods.

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