A lead-in word from one of the authors:

The first paper *contains quite a bit of mathematical stuff, but hopefully there is enough narrative to explain what is going on. This forms the basis for the rest of the work that we have done and are continuing to do; there will be at least three more papers based on this, each of which will contain not a lot of the heavy math stuff because it is pretty well all in here.*

The second paper *is a kind of field handbook to using the technique described in paper 1. The technique is referred to as the critical distance method; you may notice a similarity to critical separation in the name. It is deliberate, and when you look at this paper you will see why.*

The third paper *is a graph and a table of numbers that go with paper 2.*

The fourth paper *is a draft of our latest work.*

Dave Perkins
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Lateral Range Curves, Search Probabilities, and Grid Searching

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Abstract

The Lateral Range Curve is a fundamental component of search theory, but its importance is not always appreciated and it is often misunderstood. This paper looks at two lateral range curves in some detail, and highlights the difference between the probability of the searcher detecting a search object as demonstrated by the lateral range curve, and the probability of the searcher detecting a search object in the generally accepted meaning of the term "probability of detection", POD.

It goes on to consider the problem of grid searching, and shows how each of the lateral range curves gives rise to a distinct and different graph of POD as a function of Coverage.

The paper is of necessity mathematical in nature, but there is sufficient non-mathematical content to put the principles within the reach of most land SAR searchers, and to provide them with a good basis for understanding the application of search theory to land SAR.

An Introduction to Lateral Range Curves

Imagine a searcher following an infinitely long, straight path, searching on either side of that path. That searcher's Lateral Range Curve $p(x)$ is the probability of detecting a stationary object that is **at its closest exactly** a distance x from the searcher's path on the ground.[1] Note, this is not the usual probability of detection (POD), which is the probability of detecting an object that is **within** a distance x of the searcher's path. This distinction has been not been made by some authors and has lead to confusion.[2]

By convention, the searcher's path is assumed to be $x = 0$, with $x > 0$ being to the searcher's right, and $x < 0$ to the searcher's left.

There are an infinite number of possible Lateral Range Curves (LRCs), three examples of which follow.[3] In these examples, the quantity M is a positive constant.

- **The Definite Range Lateral Range Curve Model**

$$p(x) = \begin{cases} 1 & \text{if} \quad -M/2 \leq x \leq M/2, \\ 0 & \text{if} \quad |x| > M/2. \end{cases}$$

[1] In the case of an aircraft, x, is measured from the object to the projection of the flight-path on the ground.

[2] See, for example, "Overview of Search Theory, Part 1" by Lee Lang, *Technical Rescue*, Issue 50, 2007, page 30.

[3] See also "Search and Screening" by Bernard O. Koopman, MORS, Virginia, 1999, page 64, and "Search and Detection" by Alan R. Washburn, INFORMS, Maryland, 4th edition, 2002, Chapter 4.

Where it is not zero, this is a rectangle of height 1 and base-length M.

- **The Linear Lateral Range Curve Model**

$$p(x) = \begin{cases} 1 - \frac{|x|}{M} & \text{if} \quad -M \leq x \leq M, \\ 0 & \text{if} \quad |x| > M. \end{cases}$$

Where it is not zero, this is an isosceles triangle with height 1 and base length $2M$.

- **The Inverse Cube Lateral Range Curve Model**

$$p(x) = \begin{cases} 1 - e^{-M^2/(4\pi x^2)} & \text{if} \quad x \neq 0, \\ 1 & \text{if} \quad x = 0. \end{cases}$$

This is a bell-shaped curve that is never zero.

Figure 1 shows these functions, with $M = 1$.

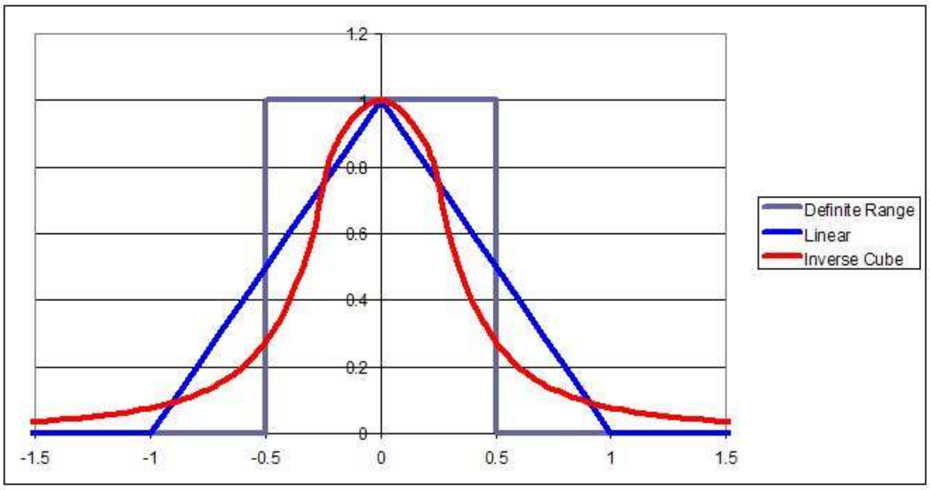


Figure 1: Lateral Range Curves

Each of these LRCs has the property that $p(0) = 1$, that is, for each of these models the probability of detecting an object that is on the searcher's path is 100%. While this may seem a reasonable property to expect of an LRC this is not be true for all situations. For example, the flight-path of a helicopter is unsearched if the pilot and co-pilot are concentrating on navigating and are not searching, while the searchers are looking out of the cargo doors and searching at right-angles to the flight-path. (This can occur when a "Huey" is used as the search platform.) Under these circumstances we have $p(0) = 0$, and none of the previous models would be useful in this case. Thus, in general, $p(0) \neq 1$.

Each of these LRCs has the property that they are symmetric about the vertical axis, that is $p(x) = p(-x)$. This means that the probability of detecting an object at distance x from the searcher's path is the same as the probability of detecting an object at distance $-x$ from the searcher's path. That is, the probability is the same to the right and left of the searcher's path. While this may seem a reasonable property to expect of an

LRC this will not be true for all situations. For example, if the searcher's path has a forest to the left and a meadow to the right, then you would not expect $p(x) = p(-x)$. The same is true for an air-scenting dog as it works across the wind trying to pick up the scent being carried downwind from a human scent source. The dog is much more likely to pick up the scent of a person who is 100 metres upwind of their path compared with 100 metres downwind of it; the dog's LRC would not be symmetrical. Thus, in general, $p(x) \neq p(-x)$.

A LRC is a characteristic of a sensor, searching for a particular object in a particular environment. A change in any of these will bring about a change in the shape of the LRC. For example, if we replace the search objects in the original example with a different set of objects that are larger and in a high visibility colour, then, because they can be seen at a greater distance than the original objects, the three LRCs in Fig. 1 would extend out farther than they currently do.

Properties of LRCs

All LRCs share the following properties.

1. $p(x)$ is defined for all x.
2. $p(x)$ is a probability, so $0 \leq p(x) \leq 1$.
3. The area between the $p(x)$ and the x-axis is finite, so that $\int_{-\infty}^{\infty} p(x)\,dx$ converges. This area, W, is called the **Effective Sweep Width**, so

   $$W = \int_{-\infty}^{\infty} p(x)\,dx.$$

   In each of the previous three LRCs,

   $$W = M,$$

   where W is the area under the LRC. This can be shown quite easily for the Definite Range and Linear LRCs in Fig. 1 (remember that $M = 1$); the Inverse Cube Model could be dealt with in the same way but is more complicated
4. Functions whose graphs have vertical sides are allowed. This is accomplished if $p(x)$ is either continuous or has a finite number of jump discontinuities.[4]

From now on we will concentrate on the Definite Range LRC model and the Linear LRC model.

Grid Searching and Coverage

In land SAR, ground searchers generally search not on their own but as part of an organized group. However, an aircraft involved in a land search is usually searching on its own, and will most likely be flying a search pattern called a creeping line; that is beyond the scope of the current document and will be dealt with in a later paper.

The basic method of searching areas in the later stages of a land search for a missing person is grid searching. In grid searching, the searchers in a field team form a line with equal spacing between adjacent searchers at the start of the area they are to search. This has the effect of defining, on the ground ahead of

[4] A jump discontinuity of a function $f(x)$ is a point a where the limit of $f(x)$ as x approaches a from the left and the corresponding limit from the right both exist but are distinct.

each searcher, a strip of ground that is their responsibility to search. The center line of this strip of ground and its projection forward through the search area represents the ideal path along which the searcher would move. The search field team then moves forward together, maintaining the original spacing. The searchers are moving forward together in a series of regularly spaced parallel paths.

We let the track spacing (the distance between the parallel paths) be nW, where W is the effective sweep width and $n > 0$. The coverage, C, is calculated as the ratio of the search effort to the area of the sector being searched, which is

$$C = \frac{\text{Total distance travelled by the searchers} \times \text{ Effective sweep width}}{\text{Area of the sector}},$$

and it can be easily shown that this is equivalent to

$$\begin{aligned} C &= \frac{\text{Effective sweep width}}{\text{Track spacing}} \\ &= \frac{W}{nW} \\ &= \frac{1}{n}. \end{aligned}$$

In other words, as the spacing decreases (n gets smaller) and the searchers get closer together then the coverage C increases; as the spacing increases (n gets larger) and the searchers get further apart then the coverage C decreases.

In the analysis that follows, we will examine the effect that varying the spacing between adjacent searchers has on the POD of a line of grid searchers. We will consider searcher spacings from wide apart ($n > 1$ and $C < 1$) to close together ($n = \frac{1}{2}$ and $C = 2$). We will do this for both the Definite Range LRC and the Linear LRC. The analysis assumes that all of the searchers are at the same spacing, and that the spacing remains constant throughout. It also assumes that the search object is between the searchers.

Grid Search: Definite Range LRC Model

A field team consists of a number of searchers operating together. Each searcher can be represented by a lateral range curve. The method used to calculate their POD is to place a copy of the lateral range curve for each searcher next to each other at a common distance nW apart.

The formula $C = 1/n$ gives the coverage for this distance and therefore the POD can be determined for various values of coverage.

Figures 2 and 3 represent the two different situations that need to be considered regarding the spacing between two searchers.

Figure 2 represents two searchers separated by a distance nW where $n \geq 1$. Here the searchers are sufficiently far apart for there to be no overlap of the lateral range curves. This means that, depending on its position, there is a chance that an object between the two searchers will be seen by either of them or by neither of them. It is not possible for both of them to see it.

Figure 3 represents two searchers separated by a distance nW where $n \leq 1$. Here the lateral range curves overlap in the area between the searchers. In this case, depending on its position, there is a chance that one or both of the searchers could see the search object that is situated in the region between them.

In Fig. 2 the coverage C is in the range $0 < C \leq 1$; in Fig. 3 it is in the range $C \geq 1$. This provides a useful check on the calculation process in that the POD for the end values for the ranges ($C = 1$) should be the same whichever range has been considered.

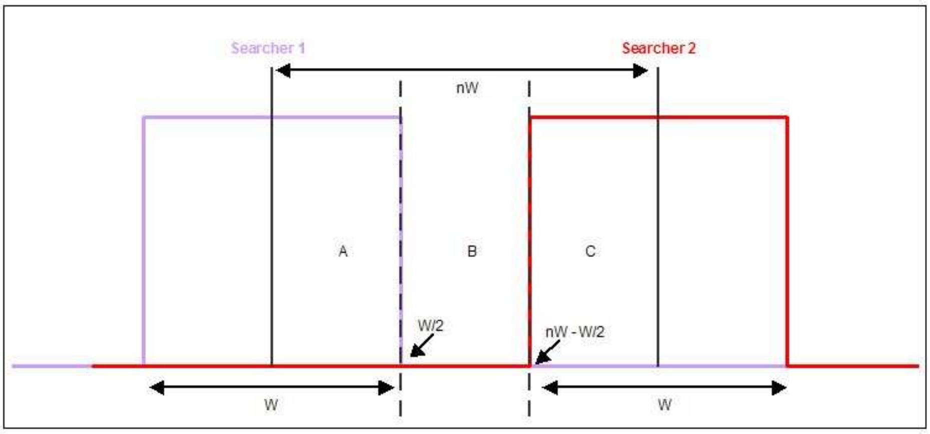


Figure 2: Two searchers separated by nW, where $n \geq 1$

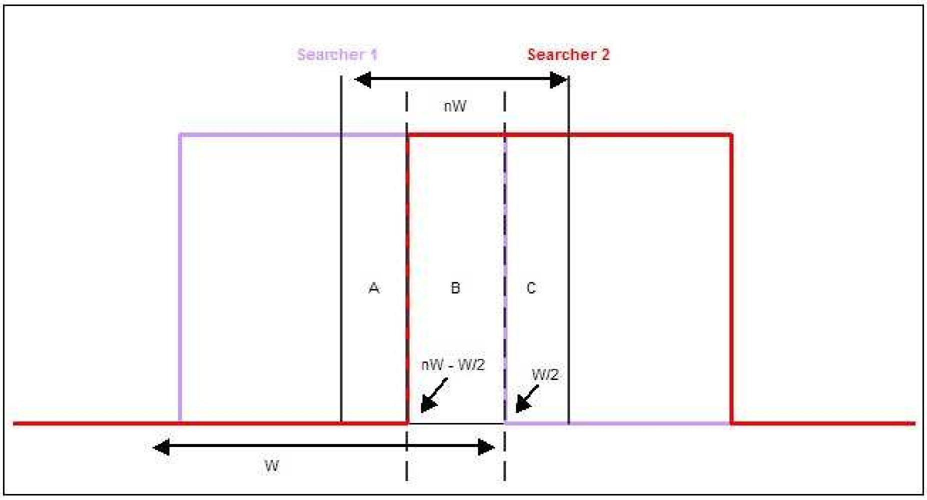


Figure 3: Two searchers separated by nW, where $0.5 \leq n \leq 1$

If $p_k(x)$ represents the probability that an object at distance x is seen by searcher k, and $\widetilde{p_k}(x) = 1 - p_k(x)$ the probability that it is not seen by searcher k then the probability $P(x)$ that this object is seen by either searcher 1 or by searcher 2 or by both is given by

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x).$$

Then the probability of seeing an object located anywhere in a rectangular region of height 1 whose base starts at $x = a$ and ends at $x = b$ (where $a < b$), is given by

$$\int_a^b P(x)\,dx.$$

POD for Coverage ≤ 1

In Fig. 2 we see that there are three regions to consider, A, B, and C.

For an object located in region A at a distance x from searcher 1 we have $0 \leq x \leq W/2$, so $p_1(x) = 1$ and $\widetilde{p_1}(x) = 1 - p_1(x) = 0$. We also have $p_2(x) = 0$ and $\widetilde{p_2}(x) = 1 - p_2(x) = 1$, so that the probability that the object at a distance x from searcher 1 is seen is

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1.$$

Thus, the probability of seeing an object located anywhere in region A is

$$P_A = \int_0^{W/2} P(x)\,dx = \int_0^{W/2} 1\,dx = \frac{W}{2}.$$

In the same way, we find that the probability of seeing an object located anywhere in region B is $P_B = 0$, and the probability of seeing an object located anywhere in region C is $P_C = W/2$. Notice that $P_A = P_C$, as expected by symmetry.

Thus, the probability of detection for an object located anywhere between searcher 1 and searcher 2 in Fig. 2 is

$$POD = \frac{\text{Total number of objects that are found}}{\text{Total number of objects that are available to be found}}.$$

The numerator is the sum of the probabilities for the three regions A, B and C, which is equivalent to the total number of objects found between the two searchers; the denominator is $nW \times 1$, which is the area of the rectangle in Fig. 2 between the searchers that contains all of the search objects. Thus,

$$POD = \frac{P_A + P_B + P_C}{nW} = \frac{W/2 + 0 + W/2}{nW} = \frac{1}{n} = C.$$

POD for Coverage $1 \leq C \leq 2$

In Fig. 3 we see that there are again three regions to consider, A, B, and C.

For an object located in region A at a distance x from searcher 1 we have $0 \leq x \leq nW - W/2$, so $p_1(x) = 1$ and $\widetilde{p_1}(x) = 1 - p_1(x) = 0$. We also have $p_2(x) = 0$ and $\widetilde{p_2}(x) = 1 - p_2(x) = 1$, so that

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1.$$

Thus, the probability of seeing an object located anywhere in region A is

$$P_A = \int_0^{nW-W/2} 1\,dx = nW - \frac{W}{2}.$$

For an object located in region B at a distance x from searcher 1 we have $nW - W/2 \le x \le W/2$, so $p_1(x) = 1$ and $\widetilde{p_1}(x) = 1 - p_1(x) = 0$. We also have $p_2(x) = 1$ and $\widetilde{p_2}(x) = 1 - p_2(x) = 0$, so that

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1.$$

Thus, the probability of seeing an object located anywhere in region B is

$$P_B = \int_{nW-W/2}^{W/2} 1\,dx = \frac{W}{2} - \left(nW - \frac{W}{2}\right) = W - nW.$$

For an object located in region C at a distance x from searcher 1 we have $W/2 \le x \le nW$, so $p_1(x) = 0$ and $\widetilde{p_1}(x) = 1 - p_1(x) = 1$. We also have $p_2(x) = 1$ and $\widetilde{p_2}(x) = 1 - p_2(x) = 0$, so that

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1.$$

Thus, the probability of seeing an object located anywhere in region C is

$$P_C = \int_{W/2}^{nW} 1\,dx = nW - \frac{W}{2}.$$

Notice that $P_A = P_C$, as expected by symmetry.

Thus, the probability of detection for an object located anywhere between searcher 1 and searcher 2 in Fig. 3 is

$$POD = \frac{P_A + P_B + P_C}{nW} = \frac{(nW - W/2) + (W - nW) + (nW - W/2)}{nW} = 1.$$

Thus, we have

$$POD(C) = \begin{cases} 1 & \text{if} \quad 1 \le C \le 2, \\ C & \text{if} \quad 0 < C \le 1. \end{cases}$$

As a check, we see that when $C = 1$ then $POD(C) = 1$ in both cases.

Grid Search: Linear LRC Model

We now repeat this process for the Linear LRC Model.

A field team consists of a number of searchers operating together. Each searcher can be represented by a lateral range curve. The method used to calculate their POD is to place a copy of the lateral range curve for each searcher next to each other at a common distance nW apart. Thus, searcher 1's lateral range curve intersects the horizontal axis at $-W$ and W. Searcher 2 is immediately to searcher 1's right a distance nW from searcher 1, so searcher 2's lateral range curve intersects the horizontal axis at $nW - W$ and $nW + W$. Searcher 3 is immediately to searcher 2's right a distance $2nW$ from searcher 1, so searcher 3's lateral range curve intersects the horizontal axis at $2nW - W$ and $2nW + W$. And so on. In the same way, Searcher 0 is immediately to searcher 1's left a distance nW from searcher 1, so searcher 0's lateral range curve intersects the horizontal axis at $-nW - W$ and $-nW + W$.

Notice that although we will be following a similar approach to that used for the Definite Range model, for some of the time we will have to take into account searchers on either side of the two searchers on whom our attention is focused. This is because when coverage $C > 1$, the spacing between adjacent searchers is less than W, and consequently there is a chance that these outer searchers could detect an object in the space that we are examining.

There are various possibilities that occur as n decreases, and more and more of these lateral range curves overlap. Each of the four cases that follow is described in terms of the relationships between the points where the LRCs meet the horizontal axis in the space between searcher 1 and searcher 2. Start with the first point that occurs to the right of searcher 1 in the appropriate diagram, work towards and finish with searcher 2; remember that searcher 2 is always at a distance nW from searcher 1.

1. For large n, none of the lateral range curves will intersect, which occurs when the right-hand intersection of searcher 1's lateral range curve is less than the left-hand intersection of searcher 2's lateral range curve. This occurs when $W \leq W(n-1)$, that is, $n \geq 2$ or $C \leq 0.5$.

   Figure 4 represents two searchers separated by a distance nW where $n \geq 2$. Here the searchers are sufficiently far apart for there to be no overlap of the lateral range curves. This means that, depending on its position, there is a chance that an object between the two searchers will be seen by either of them or by neither of them. It is not possible for both of them to see it.

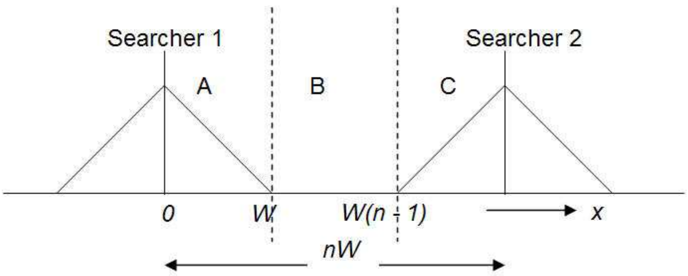


Figure 4: Two searchers separated by nW, where $n \geq 2$

2. The next change occurs when searcher 2's left-hand intersection is inside searcher 1's right-hand intersection, but searcher 3's left-hand intersection is not inside searcher 1's right-hand intersection. This occurs when $W(n-1) \leq W \leq nW$, that is, $1 \leq n \leq 2$ or $0.5 \leq C \leq 1$.

   Figure 5 represents two searchers separated by a distance nW where $1 \leq n \leq 2$. Here the lateral range curves overlap in the area between the searchers. In this case, depending on its position, there is a chance that one or both of the searchers could see the search object that is situated in the region between them.

3. The next change occurs when searcher 3's left-hand intersection is inside searcher 1's right-hand intersection, but is not inside searcher 0's right-hand intersection. This occurs when $(1-n)W \leq (2n-1)W \leq nW$, that is, $2/3 \leq n \leq 1$ or $1 \leq C \leq 1.5$.

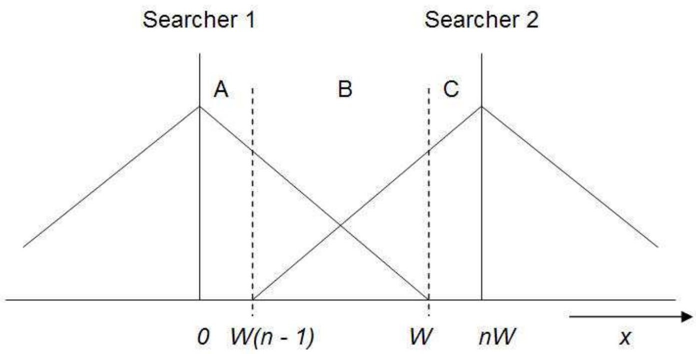


Figure 5: Two searchers separated by nW, where $1 \leq n \leq 2$

Figure 6 represents four searchers separated by a distance nW where $2/3 \leq n \leq 1$. Here the searchers are sufficiently close not only for their lateral range curves to overlap but there is now a chance that searchers 0 and 3 will see the search object in the region between searchers 1 and 2.

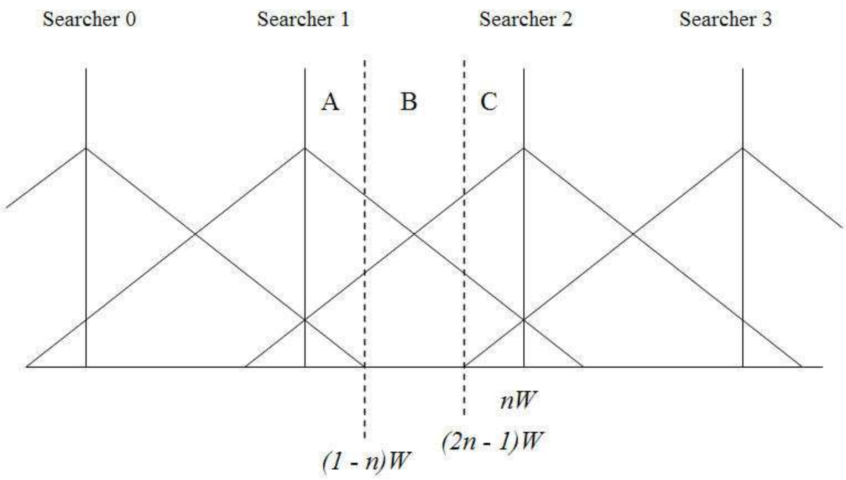


Figure 6: Four searchers separated by nW, where $2/3 \leq n \leq 1$

4. The final case occurs when searcher 3's left-hand intersection is inside searcher 0's right hand intersection. This occurs when $(2n-1)W \leq (1-n)W \leq nW$, that is, $1/2 \leq n \leq 2/3$, or $1.5 \leq C \leq 2$.

   Figure 7 represents four searchers separated by a distance nW where $1/2 \leq n \leq 2/3$. Here the searchers are sufficiently close not only for their lateral range curves to overlap but there is now a chance that that searchers 0 and 3 will see the search object in the region between searchers 1 and 2.

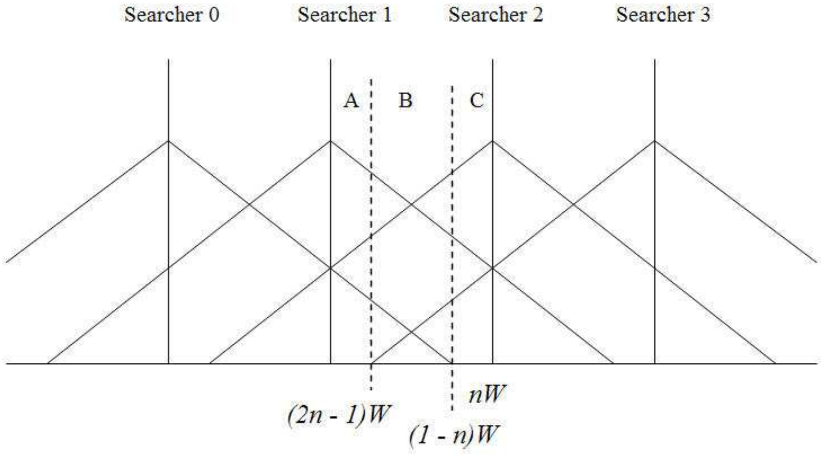


Figure 7: Four searchers separated by nW, where $1/2 \leq n \leq 2/3$

The procedure that we will use to determine the POD for a grid search team is to take each of the four cases that we have just identified, and in each case calculate the POD for the area between searchers 1 and 2. This will give the POD between any two adjacent searchers, and therefore by extension give the POD anywhere between the searchers at either end of the line. The corresponding results for the regions to the left of left-most searcher and to the right of right-most searcher require a different analysis, and will be dealt with in a later paper.

POD for Coverage ≤ 0.5

In Fig. 4 we see that there are three regions to consider, A, B, and C.

For an object located in region A at a distance x from searcher 1 we have $0 \leq x \leq W$, so $p_1(x) = 1 - x/W$ and $\widetilde{p_1}(x) = 1 - p_1(x) = x/W$. We also have $p_2(x) = 0$ and $\widetilde{p_2}(x) = 1 - p_2(x) = 1$, so that the probability that the object at a distance x from searcher 1 is seen is

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1 - \frac{x}{W}.$$

Thus, the probability of seeing an object located anywhere in region A is

$$P_A = \int_0^W \left(1 - \frac{x}{W}\right) dx = \frac{W}{2}.$$

For an object located in region B at a distance x from searcher 1, we have $W \leq x \leq (n-1)W$, so $p_1(x) = 0$ and $\widetilde{p_1}(x) = 1 - p_1(x) = 1$. We also have $p_2(x) = 0$ and $\widetilde{p_2}(x) = 1$. Thus, the probability of seeing an object located anywhere in region B is

$$P_B = \int_W^{(n-1)W} (1-1)\, dx = 0.$$

For an object located in region C at a distance x from searcher 1, we have $(n-1)W \le x \le nW$, so $p_1(x) = 0$ and $p_2(x) = 1 - (nW - x)/W$, giving $\widetilde{p_1}(x) = 1$ and $\widetilde{p_2}(x) = (nW - x)/W$. Thus, the probability of seeing an object located anywhere in region C is

$$P_C = \int_{(n-1)W}^{nW} \left(1 - \frac{(nW - x)}{W}\right) dx = \frac{W}{2}.$$

Notice that $P_A = P_C$, as expected by symmetry.

Thus, the probability of detection for an object located anywhere between searcher 1 and searcher 2 in Fig. 4 is

$$POD = \frac{P_A + P_B + P_C}{nW} = \frac{W/2 + 0 + W/2}{nW} = \frac{1}{n} = C.$$

POD for Coverage $0.5 \le C \le 1$

In Fig. 5 we see that there are again three regions to consider, A, B, and C.

For an object located in region A at a distance x from searcher 1 we have $0 \le x \le (n-1)W$, so $p_1(x) = 1 - x/W$ and $\widetilde{p_1}(x) = 1 - p_1(x) = x/W$. We also have $p_2(x) = 0$ and $\widetilde{p_2}(x) = 1 - p_2(x) = 1$, so that

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1 - \frac{x}{W}.$$

Thus, the probability of seeing an object located anywhere in region A is

$$P_A = \int_0^{(n-1)W} \left(1 - \frac{x}{W}\right) dx = \frac{W}{2}(4n - n^2 - 3).$$

For an object located in region B at a distance x from searcher 1, we have $(n-1)W \le x \le W$, so $p_1(x) = 1 - x/W$ and $\widetilde{p_1}(x) = 1 - p_1(x) = x/W$. We also have $p_2(x) = 1 - (nW - x)/W$ and $\widetilde{p_2}(x) = (nW - x)/W$, so that

$$P(x) = 1 - \widetilde{p_1}(x)\widetilde{p_2}(x) = 1 - \frac{x}{W}\frac{nW - x}{W} = \frac{1}{W^2}(W^2 - nWx + x^2).$$

Thus, the probability of seeing an object located anywhere in region B is

$$P_B = \frac{1}{W^2} \int_{(n-1)W}^{W} (W^2 - nWx + x^2)\, dx = \frac{W}{6}(n^3 - 12n + 16).$$

For an object located in region C at a distance x from searcher 1, we have $W \le x \le nW$, so $p_1(x) = 0$ and $p_2(x) = 1 - (nW - x)/W$, giving $\widetilde{p_1}(x) = 1$ and $\widetilde{p_2}(x) = (nW - x)/W$. Thus, the probability of seeing an object located anywhere in region C is

$$P_C = \int_W^{nW} \left(1 - \frac{(nW - x)}{W}\right) dx = \frac{W}{2}(4n - n^2 - 3).$$

Notice that $P_A = P_C$, as expected by symmetry.

Thus, the probability of detection for an object located anywhere between searcher 1 and searcher 2 in Fig. 5 is

$$POD = \frac{P_A + P_B + P_C}{nW} = \frac{2\frac{W}{2}(4n - n^2 - 3) + \frac{W}{6}(n^3 - 12n + 16)}{nW},$$

which reduces to

$$POD = \frac{n^3 - 6n^2 + 12n - 2}{6n} = \frac{1 - 6C + 12C^2 - 2C^3}{6C^2}.$$

POD for Coverage $1 \leq C \leq 1.5$

In Fig. 6 we see that, if we concentrate on the area between searchers 1 and 2, there are again three regions to consider, A, B, and C.

For an object located in region A at a distance x from searcher 1 we have $0 \leq x \leq (1-n)W$, so $p_0(x) = 1-(nW+x)/W$, $p_1(x) = 1-x/W$, $p_2(x) = 1-(nW-x)/W$ and $p_3(x) = 0$. Thus,

$$P(x) = 1 - \widetilde{p_0}(x)\widetilde{p_1}(x)\widetilde{p_2}(x)\widetilde{p_3}(x) = 1 - \frac{nW+x}{W}\frac{x}{W}\frac{nW-x}{W} = \frac{W^3 - n^2W^2x + x^3}{W^3}.$$

Thus, the probability of seeing an object located anywhere in region A is

$$P_A = \frac{1}{W^3}\int_0^{(1-n)W} (W^3 - n^2W^2x + x^3)\,dx = \frac{W}{4}(5 - 8n + 4n^2 - n^4).$$

For an object located in region B at a distance x from searcher 1 we have $(1-n)W \leq x \leq (2n-1)W$, so $p_0(x) = 0$, $p_1(x) = 1-x/W$, $p_2(x) = 1-(nW-x)/W$ and $p_3(x) = 0$. Thus,

$$P(x) = 1 - \widetilde{p_0}(x)\widetilde{p_1}(x)\widetilde{p_2}(x)\widetilde{p_3}(x) = 1 - \frac{x}{W}\frac{nW-x}{W} = \frac{W^2 - Wnx + x^2}{W^2}.$$

Thus, the probability of seeing an object located anywhere in region B is

$$P_B = \frac{1}{W^2}\int_{(1-n)W}^{(2n-1)W} (W^2 - Wnx + x^2)\,dx = \frac{W}{6}(9n^3 - 24n^2 + 36n - 16).$$

For an object located in region C at a distance x from searcher 1 we have $(2n-1)W \leq x \leq nW$, so $p_0(x) = 0$, $p_1(x) = 1-x/W$, $p_2(x) = 1-(nW-x)/W$ and $p_3(x) = 1-(2nW-x)/W$.

$$P(x) = 1 - \widetilde{p_0}(x)\widetilde{p_1}(x)\widetilde{p_2}(x)\widetilde{p_3}(x) = 1 - \frac{x}{W}\frac{nW-x}{W}\frac{2nW-x}{W} = \frac{W^3 - 2xn^2W^2 + 3x^2nW - x^3}{W^3}.$$

Thus, the probability of seeing an object located anywhere in region C is

$$P_C = \frac{1}{W^3}\int_{(2n-1)W}^{nW} (W^3 - 2xn^2W^2 + 3x^2nW - x^3)\,dx = \frac{W}{4}(5 - 8n + 4n^2 - n^4).$$

Notice that $P_A = P_C$, as expected by symmetry.

Thus, the probability of detection for an object located anywhere between searcher 1 and searcher 2 in Fig. 6 is

$$POD = \frac{P_A + P_B + P_C}{nW} = \frac{2\frac{W}{4}(5 - 8n + 4n^2 - n^4) + \frac{W}{6}(9n^3 - 24n^2 + 36n - 16)}{nW},$$

which reduces to

$$POD = \frac{-1 + 12n - 12n^2 + 9n^3 - 3n^4}{6n} = \frac{-3 + 9C - 12C^2 + 12C^3 - C^4}{6C^3}.$$

POD for Coverage $1.5 \le C \le 2$

In Fig. 7 we see that, if we concentrate on the area between searchers 1 and 2, there are again three regions to consider, A, B, and C.

For an object located in region A at a distance x from searcher 1 we have $0 \le x \le (2n-1)W$, and

$$P(x) = 1 - \widetilde{p_0}(x)\widetilde{p_1}(x)\widetilde{p_2}(x)\widetilde{p_3}(x) = 1 - \frac{nW+x}{W}\frac{x}{W}\frac{nW-x}{W} = \frac{W^3 - xn^2W^2 + x^3}{W^3}.$$

Thus, the probability of seeing an object located anywhere in region A is

$$P_A = \frac{1}{W^3}\int_0^{(2n-1)W} (W^3 - xn^2W^2 + x^3)\,dx = 2Wn^4 - \frac{3}{4}W - 6Wn^3 + \frac{11}{2}Wn^2$$

For an object located in region B at a distance x from searcher 1 we have $(2n-1)W \le x \le (1-n)W$, and

$$P(x) = 1-\widetilde{p_0}(x)\widetilde{p_1}(x)\widetilde{p_2}(x)\widetilde{p_3}(x) = 1-\frac{nW+x}{W}\frac{x}{W}\frac{nW-x}{W}\frac{2nW-x}{W} = \frac{W^4 - 2xn^3W^3 + x^2n^2W^2 + 2x^3nW - x^4}{W^4}.$$

Thus, the probability of seeing an object located anywhere in region B is

$$P_B = \frac{1}{W^4}\int_{(2n-1)W}^{(1-n)W} (W^4 - 2xn^3W^3 + x^2n^2W^2 + 2x^3nW - x^4)\,dx = \frac{8}{5}W - \frac{9}{10}Wn^5 + 6Wn^3 - \frac{22}{3}Wn^2.$$

For an object located in region C at a distance x from searcher 1 we have $(1-n)W \le x \le nW$, and

$$P(x) = 1 - \widetilde{p_0}(x)\widetilde{p_1}(x)\widetilde{p_2}(x)\widetilde{p_3}(x) = 1 - \frac{x}{W}\frac{nW-x}{W}\frac{2nW-x}{W} = \frac{W^3 - 2xn^2W^2 + 3x^2nW - x^3}{W^3}.$$

Thus, the probability of seeing an object located anywhere in region C is

$$P_C = \frac{1}{W^3}\int_{(1-n)W}^{nW} (W^3 - 2xn^2W^2 + 3x^2nW - x^3)\,dx = 2Wn^4 - \frac{3}{4}W - 6Wn^3 + \frac{11}{2}Wn^2.$$

Notice that $P_A = P_C$, as expected by symmetry.

Thus, the probability of detection for an object located anywhere between searcher 1 and searcher 2 in Fig. 7 is

$$POD = \frac{P_A + P_B + P_C}{nW} = \frac{2\left(2Wn^4 - \frac{3}{4}W - 6Wn^3 + \frac{11}{2}Wn^2\right) + \left(\frac{8}{5}W - \frac{9}{10}Wn^5 + 6Wn^3 - \frac{22}{3}Wn^2\right)}{nW},$$

which reduces to

$$POD = \frac{3 + 110n^2 - 180n^3 + 120n^4 - 27n^5}{30n} = \frac{-27 + 120C - 180C^2 + 110C^3 + 3C^5}{30C^4}.$$

Putting these together we find

$$POD(C) = \begin{cases} C & \text{if} \quad 0 < C \le 0.5, \\ \frac{1-6C+12C^2-2C^3}{6C^2} & \text{if} \quad 0.5 \le C \le 1, \\ \frac{-3+9C-12C^2+12C^3-C^4}{6C^3} & \text{if} \quad 1 \le C \le 1.5, \\ \frac{-27+120C-180C^2+110C^3+3C^5}{30C^4} & \text{if} \quad 1.5 \le C \le 2. \end{cases}$$

The end values ($C = 0.5, 1$, and 1.5) once again provide a useful check.

Figure 8 shows these PODs as a function of coverage for the Definite Range and Linear LRCs.

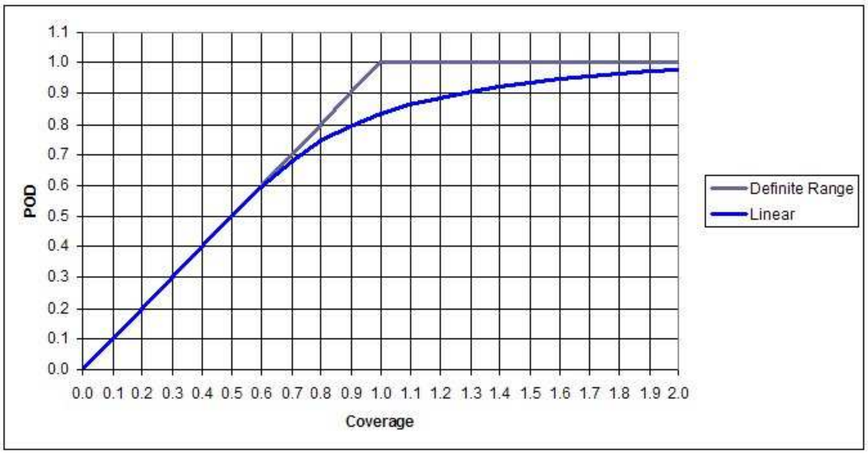


Figure 8: POD versus Coverage for grid search

Summary

This paper has demonstrated a number of points which may help to provide an understanding of the application of search theory to land SAR.

1. A lateral range curve (LRC) describes the detection characteristics of a single sensor; there will be as many LRCs as there are combinations of sensor, search object, terrain, vegetation and visibility, that is, a very large number.
2. The probability given by a LRC relates to an object at a certain distance from the searcher's path; the accepted meaning of the term probability in POD relates to an object that is within a certain distance of the searcher's path.
3. The effective sweep width is the area under the LRC.
4. When a field team grid searches, the POD is influenced by the fact that the LRCs can overlap; the degree of overlapping, and therefore the POD, depends on the spacing between adjacent searchers.
5. Their coverage of the sector that they are searching is determined by their spacing.
6. Graphs of POD against coverage that are derived from overlapping LRCs assume that the spacing between each pair of adjacent searchers is the same and remains the same; if they are not then the graph cannot be used.

Acknowledgement

We would like to thank Alan Washburn, Emeritus Professor of Operations Research at the Naval Postgraduate School, Monterey, California, for valuable discussions and suggestions.

The Critical Distance method: estimating the Probability of Detection for Grid Searching by a Land SAR Field Team

Dave Perkins, The Centre for Search Research, Ashington, Northumberland, UK

February 2008

Abstract

There has been much discussion in recent years over the role of search theory in land SAR. This author welcomes it for the consistent, objective approach that it can provide for estimating probability of detection (POD) for a land SAR field team.

This paper takes some of the ideas discussed in an earlier paper[1] and develops them to describe a procedure for estimating grid search POD. The procedure is called the critical distance method. It is entirely self-contained: it all takes place at the time of the search, it uses data provided by the field team and it does not depend on results from prior field trials.

The linear lateral range curve

The linear lateral range curve (LLRC) forms the basis for the critical distance method. Figure 1 shows an example of a LLRC. It shows how the probability that a searcher will detect an object as they pass it by depends on the distance between the searcher and the object.

When the object is at zero distance from the searcher, the searcher is bound to see it. As the distance increases, the probability decreases at a uniform rate. Eventually, when the object is at a certain distance from the searcher, the probability that the searcher will see it becomes zero and remains at zero for all distances beyond that. In other words, there is a point at and beyond which the searcher cannot see the object. The distance between this point and the searcher is very significant, and we will refer to it as the critical distance.

Any lateral range curve, including the LLRC, relates to a particular sensor and a particular search object in a particular environment. If any of those factors change then the lateral range curve will change. To put that into a land SAR context for the LLRC, we would say that the critical distance depends on the searcher, what they are searching for, and the conditions (the terrain, vegetation and visibility) in the location where they are searching for it.

Effective sweep width

A sensor's effective sweep width is the area under its lateral range curve. It can be shown[2] that the area under the LLRC in fig.1, and therefore the effective sweep width of the human searcher it represents, is equal to the critical distance. This is an important property of the LLRC.

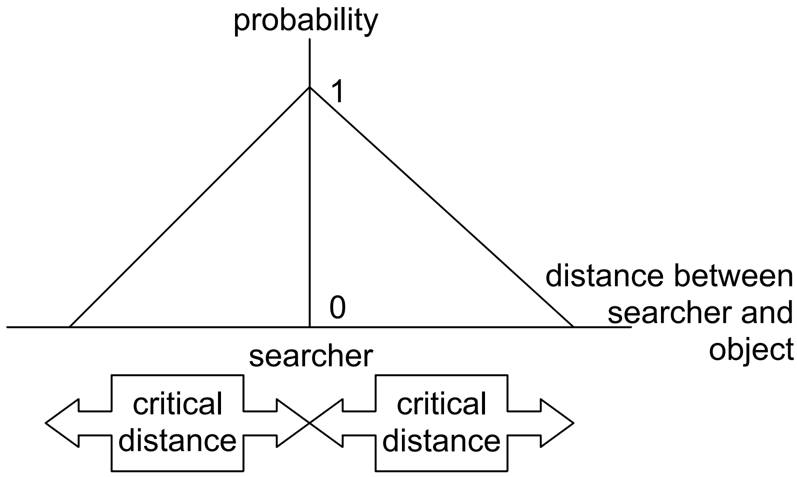


Figure 1: the linear lateral range curve (LLRC)

The LLRC in figure 1 is for one searcher. That searcher could find their critical distance (and therefore their sweep width) by the careful application of a simple field technique that would amount to little more than placing an object on the ground, walking away from it until they can no longer see it and measuring how far from it they have walked.

If each of the searchers in a field team used a similar method to find their own critical distance, the effective sweep width for the field team would be the average of these.

This is a simple description of the field technique that would enable a field team to find their effective sweep width for the missing person that they are searching for in the sector that they are assigned to search:

a. they choose a location that is typical of the sector in terms of its terrain and vegetation
b. they place an object, if possible similar in appearance to the missing person, on the ground in that location
c. they gather round the object and then walk away from it in different directions until it is no longer visible
d. they determine how far each of them has travelled
e. the effective sweep width for the field team is the average of these distances

That was a simple, outline description of the field technique. There is a more detailed description later in the paper; it is essential that anyone wishing to use the technique should read it carefully, together with the worked example and the comments that follow it.

Calculating coverage

The concept of coverage is well documented. It is sufficient here to give two ways of calculating it for a field team. If W is the effective sweep width then:

a. after the field team has searched a sector, and their average track length has been calculated, their coverage of the sector that they have just searched is given by

$$\text{coverage} = \frac{\text{average track length x W x manpower}}{\text{area of the sector}}$$

where 'manpower' means the number of searchers in the field team

b. if the field team is searching with a constant spacing of nW, where W is the effective sweep width and n > 0 is a constant, then the above formula is equivalent to

$$\text{coverage} = \frac{\text{sweep width}}{\text{spacing}} = \frac{1}{n}$$

The critical distance POD curve

The LLRC in fig. 1 shows how likely a single searcher is to detect a single object at a particular distance as they pass by it. In practice we are usually interested in how likely a group of searchers is to detect an object that lies anywhere within their overall path; this is their POD for the object in question in the environment in which they are searching.

Figure 2 shows a graph of POD versus coverage based on the LLRC; the way in which it was derived is described elsewhere.[3] The graph is referred to as the critical distance POD curve.

Grid searching

The derivation of the critical distance POD curve depends on the fact that the members of the field team are moving along parallel paths and maintaining a constant spacing between adjacent searchers. This is grid searching, or line searching, and the procedure described below should therefore only be used for that type of searching.

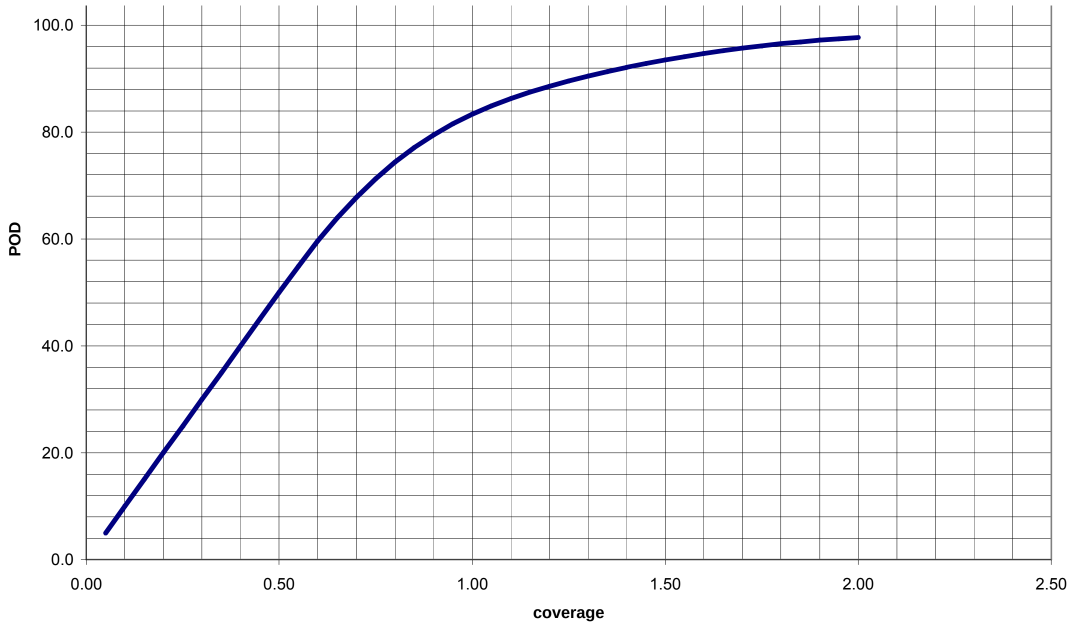


Figure 2: the critical distance POD curve

The critical distance method: a complete description of the procedure

1. Each field team should have at least one GPS; ideally, each member of the field team should carry one.
2. When they arrive at their sector, the field team needs to find a location that they consider to be representative of the sector as a whole. They should take great care to make sure that, as far as possible, its terrain and vegetation are typical of the entire sector. This is where they will determine the effective sweep width.
3. They put an object on the ground in the middle of their chosen location. They may give it an appropriately coloured covering so that it resembles the colour of the clothing worn by the missing person. A backpack is a good body substitute for an adult; if they are searching for a specific size or type of clue, or a child, then they use something that is closer in size and appearance to that search object.
4. The members of the field team gather round the object, and then walk away from it, each heading in a different direction. They look back at the object at regular intervals. Each of them is trying to find the point at which they can no longer see it as they move away from it. The exact point at which this happens for each searcher will need to be checked carefully by moving towards and then away from the object a few times. It would be useful if each searcher marked this point by putting a marker (for example a walking pole or hiking pole) on the ground.

5. The distance between a searcher's marker and the object the field team placed on the ground in step 3 is that searcher's critical distance.
6. Each searcher needs to measure their critical distance. It is sufficient to do this by pacing, provided that they can do it reliably and accurately, and can convert their paces to distances. If not, they should use some sort of measuring device. The marker that they put down should simplify this task; it also allows a second searcher to check the measurement, if necessary.
7. They inform the planner of the critical distance for each searcher; the average of these is the effective sweep width for that object in that environment for that field team. The planner records this for use in step 10.
8. Each member of the field team with a GPS sets the track length to zero, and they begin their search as instructed in their briefing.
9. When they finish, each member of the field team with a GPS reads the track length; they send all these readings to the planner.
10. The planner works out the average track length, and calculates the field team's coverage:

    $$\text{coverage} = \frac{\text{average track length x effective sweep width x manpower}}{\text{area of sector}}$$

    where 'manpower' means the number of searchers in the field team.

11. The planner then reads the POD corresponding to that coverage from the critical distance POD curve.

If the terrain, vegetation or conditions change during the search by an amount that the field team considers would affect their critical distance, they take the following action:

- they inform the command post
- they provide the command post with sufficient information to identify the portion of the sector that they have searched so far, for example the map coordinates of their current location and a description of where they have been
- they read the track lengths from each GPS they have with them and send those to the command post
- they return to step 2 and proceed as though they were about to start searching a new sector
- the planner determines the area of the portion of the sector that the field team has searched so far, calculates their coverage for it and uses the critical distance POD curve to give the POD

In most situations, the procedure just described is the preferred option. There are two alternatives:

a. In situations where the spacing between adjacent searchers can be determined easily and accurately, the following replaces steps 8 to 10 in the original procedure:

8. The searchers space themselves as instructed in their briefing.
9. They determine the spacing between adjacent searchers by some suitable method; they send this information back to the command post and commence their search.
10. The planner calculates their coverage as effective sweep width divided by spacing.

b. In situations where the field team's briefing was to search with a particular spacing, for example 'grid search at twice the sweep width', the following replaces steps 8 to 10 in the original procedure:

8. The planner calculates the spacing that is required, and informs the field team.
9. The field team space themselves at that distance using some suitable method, and commence their search.
10. The planner calculates their coverage as effective sweep width divided by spacing.

Worked example

The following example refers to distances in metres. Readers who prefer to work in non-metric units should read the word 'metres' as 'yards' whenever it occurs between here and the end of the paper. Wherever kilometres are mentioned, a distance in miles that is approximately the same is given as well.

As part of the search for a missing adult male, a six-person field team is detailed to search a sector that is roughly rectangular, nearly two and a half km long and about 400 metres wide (almost a mile and a half long by a quarter of a mile wide). Their brief is to spread themselves across the sector and search it with a constant spacing.

The missing person was wearing a red jacket when last seen, and their briefing suggests that he is likely to be still wearing it. Their brief is to search for an adult male in a red jacket, who is on the ground and non-responsive.

When they reach the sector, they cover a backpack with a red jacket that they have with them, and lay it on the ground to find their critical distances. These are the six values (in metres) from the six members of the field team: 43, 41, 42, 44, 40 and 42. They radio these back to the command post, and the planner calculates that the average is 42 metres. Therefore, for that field team, in that sector and under those current conditions, the effective sweep width is 42 metres when looking for an adult on the ground wearing a red jacket.

They then space themselves across the sector, with the two outer searchers half a spacing from the sector boundaries[4]. Four members of the team have a GPS with them, and they each reset the track length to zero. The team then starts searching. When they reach the end of the sector and finish searching, those same four searchers read the track length from their GPS, and radio them back to the command post. The four track lengths are 2.33 km, 2.35 km, 2.32 km and 2.36 km; the planner works out the average as 2.34 km. (Note that 1 km is 1000 metres, and so the track lengths for the four searchers are 2330, 2350, 2320 and 2360 metres respectively, and the average is 2340 metres).

The planner has already established that the area of the sector is 0.85 sq. km (850,000 sq. metres) and can now calculate the field team's coverage:

$$\text{coverage} = \frac{\text{average track length x effective sweep width x manpower}}{\text{area of sector}}$$

$$= \frac{\text{2340 metres x 42 metres x 6 searchers}}{\text{850, 000 sq. metres}}$$

$$= 0.69$$

From the critical distance POD curve, the planner reads that coverage of 0.69 corresponds to a POD of 67%. The field team's POD was therefore 67% for that sector.

Comments on the worked example

1. The three measurements in the coverage formula (average track length, effective sweep width and the area of the sector) all need to be expressed in the same kind of unit (metres and square metres in the example).
2. The members of the field team perform two important tasks; the first is selecting a location that is representative of the whole sector, and the second is estimating their critical distances in that location. There are training implications here.

Summary

1. the critical distance method is based on a straightforward field technique
2. both the field technique and the critical distance POD graph are based on the same model of searcher performance
3. the critical distance method enables grid search teams to find their POD at the time of the search; it therefore reflects the current conditions
4. the field technique can be adapted to conform to the appearance of the missing person
5. as with any other new procedure, there are training implications

The critical distance POD curve

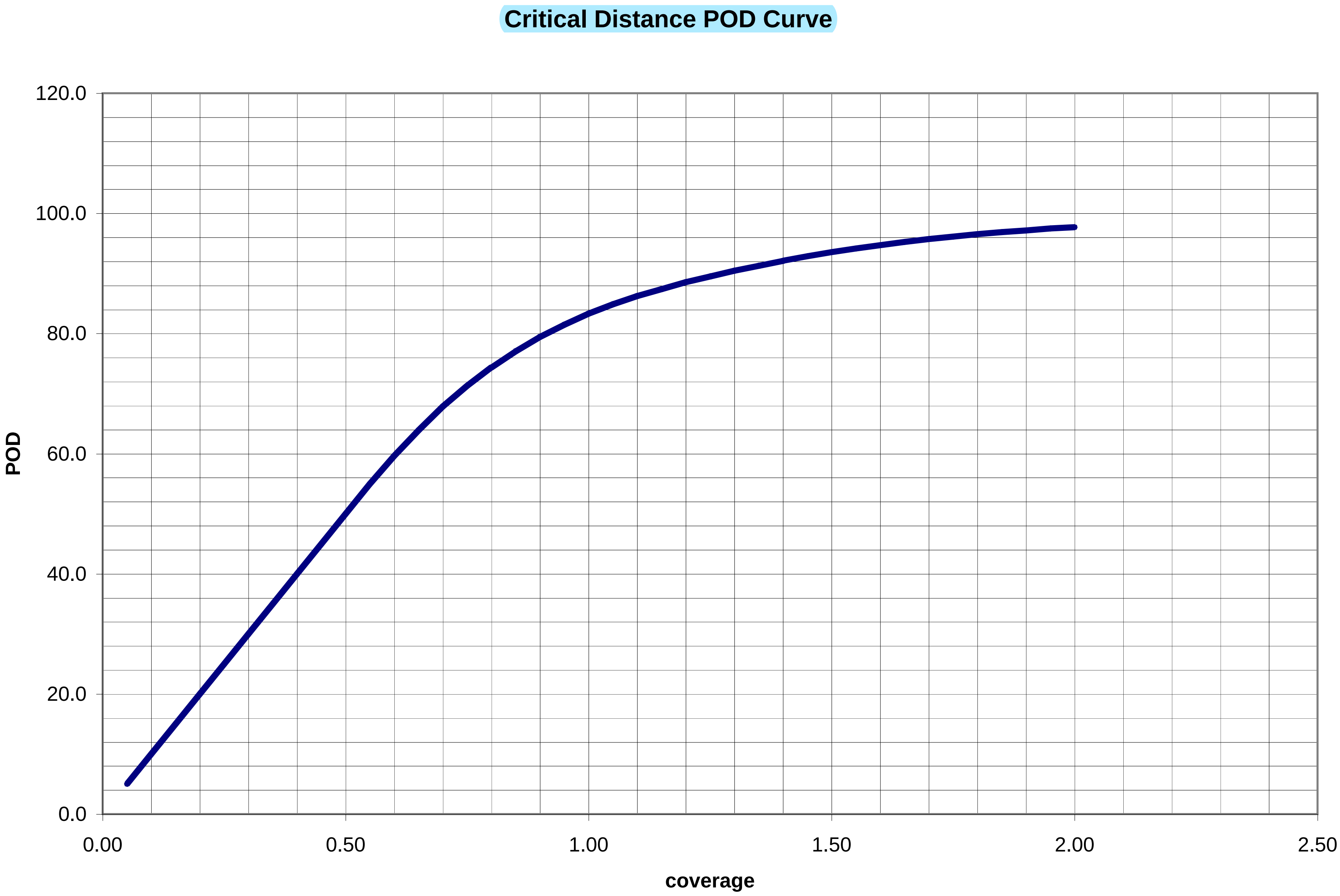
A full page version of the graph in figure 2 is available on the websites for The Centre for Search Research and The International SAR Alliance (see reference 1 for the web addresses). It will be easier to use than the graph on page 4. The numerical values that make up the graph are on page 2 of the pdf for those who either want to construct their own graph or prefer to use a table of numbers instead of a graph.

References

1 Perkins, D. and Lovelock, D., 2008, Lateral Range Curves, Search Probabilities and Grid Searching, available at www.isaralliance.com and www.searchresearch.co.uk
2 ibid, page 3
3 ibid, pages 7 to 14
4 ibid, page 10; although this is common practice, the positioning of the end searcher at half a spacing from a sector boundary will not always ensure that the POD for the line of searchers extends all the way to that boundary; this issue will be dealt with in a later paper

Acknowledgement

The author acknowledges the advice, assistance and encouragement provided by David Lovelock, Department of Mathematics, University of Arizona, Tucson, throughout the time spent in the production of this paper.


Critical Distance POD Curve
120.0
100.0
80.0
60.0
40.0
20.0
0.0
POD
0.00
0.50
1.00
1.50
2.00
2.50
coverage

coverage	POD
0.05	5.0
0.10	10.0
0.15	15.0
0.20	20.0
0.25	25.0
0.30	30.0
0.35	35.0
0.40	40.0
0.45	45.0
0.50	50.0
0.55	54.9
0.60	59.6
0.65	63.9
0.70	67.8
0.75	71.3
0.80	74.4
0.85	77.1
0.90	79.5
0.95	81.5
1.00	83.3
1.05	84.9
1.10	86.2
1.15	87.5
1.20	88.6
1.25	89.6
1.30	90.5
1.35	91.3
1.40	92.1
1.45	92.8
1.50	93.5
1.55	94.1
1.60	94.7
1.65	95.2
1.70	95.7
1.75	96.1
1.80	96.5
1.85	96.9
1.90	97.2
1.95	97.5
2.00	97.7

Critical Separation and the Probability of Detection for Grid Searching by a Land SAR Field Team

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July 2008

Abstract

This paper builds on the two earlier papers[1,2] that introduced the concepts of the linear lateral range curve and critical distance. It shows how critical separation can be used to provide an estimate of the probability of detection (POD) for land SAR field teams grid searching at any constant spacing.

The method consists of field procedures and simple calculations. If these are performed carefully, then the resulting PODs will be as reliable and robust as the values arising from the use of the critical distance method.

Critical separation, critical distance and effective sweep width

Critical separation[3] has been around for a number of years, and is familiar to a large proportion of the land SAR community. Critical distance has been around for a short while only, and has yet to reach the same level of acceptance. They are different aspects of the same phenomenon and are linked by a simple relationship.

Critical separation (CS) is defined as the spacing between two searchers such that an object placed midway between them is at the limit of visibility of both of them. Critical distance is defined as the distance from a searcher to an object that is at the limit of that searcher's visibility. Therefore for a particular object in a particular location

$$CS = 2 \times \text{critical distance.}$$

But critical distance can be taken to be the effective sweep width[4] (W), and so

$$CS = 2 \times W \qquad (1)$$

Searcher spacing, coverage and POD

Suppose that a field team is grid searching with a constant and equal spacing between adjacent searchers of k x CS, where k > 0 is a constant; for example, if the searchers are at critical separation then k = 1. From equation (1), CS is 2W, and so we can express the spacing as spacing = k x 2W

For searchers who maintain a constant and equal spacing, coverage C is given by

$$C = \frac{\text{effective sweep width}}{\text{spacing}}$$

$$= \frac{W}{2kW} \quad \text{which reduces to}$$

$$C = \frac{1}{2k}$$

Therefore each value of k has an associated level of coverage, and we can use the critical distance POD graph[5] to give the POD for that level of coverage. Thus we have a relationship between k and POD for grid searching. This can be represented by a graph, and is shown as figure 1. This is referred to as the CS POD graph. A full page version, together with the values of k, C and POD that make up the graph is given at the end of this paper.

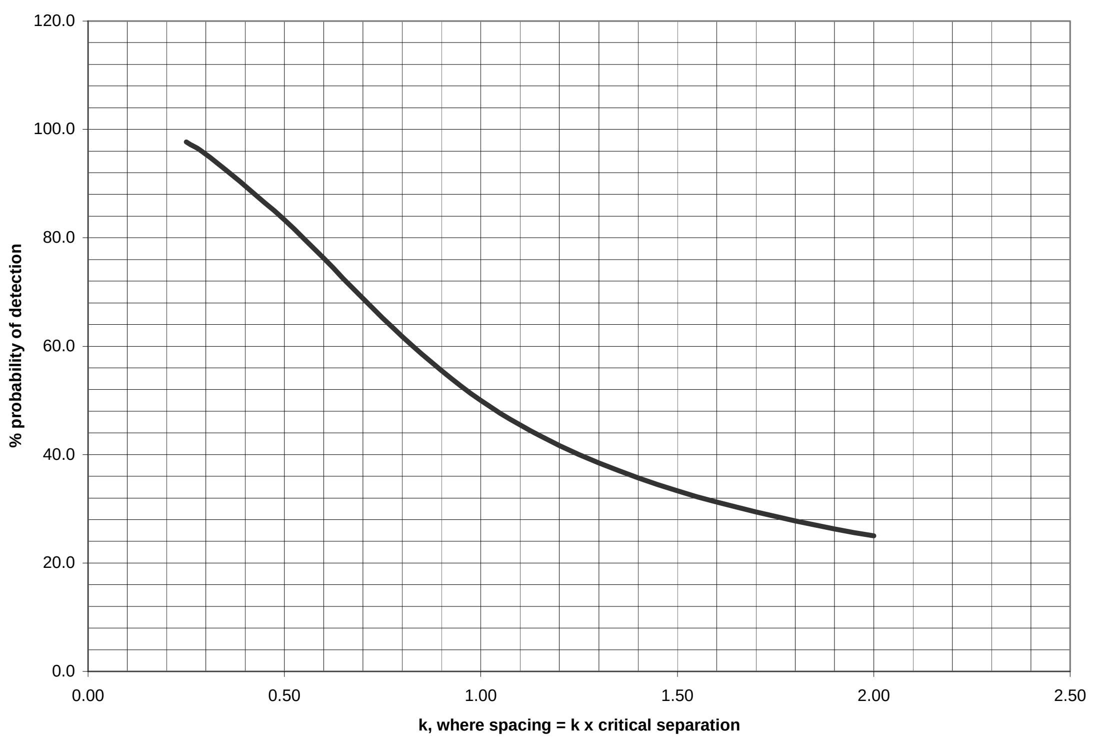

Figure 1: the critical separation POD graph

Figure 1 shows the POD associated with a range of values of searcher spacing, from 0.25 x CS to 2 x CS. For grid searching at CS (k = 1) the graph shows that the POD is 50%; for grid searching at half CS (k = 0.5) the graph shows that the POD is 83%.

The area searched

The calculation of coverage takes into account the area that has been searched. The field team, who are searching with a constant and equal spacing, are searching a corridor whose area is given by

area = corridor length x corridor width

The corridor length is the distance that they travel, and the corridor width is the distance spanned by the line of searchers. For the purpose of this paper we will assume that the distance spanned by the line of searchers is equal to the distance from a point that is a half-spacing outside the searcher at one end of the line to a point that is a half-spacing outside the searcher at the other end of the line[6]. Therefore the corridor width is

width = number of searchers x searcher spacing

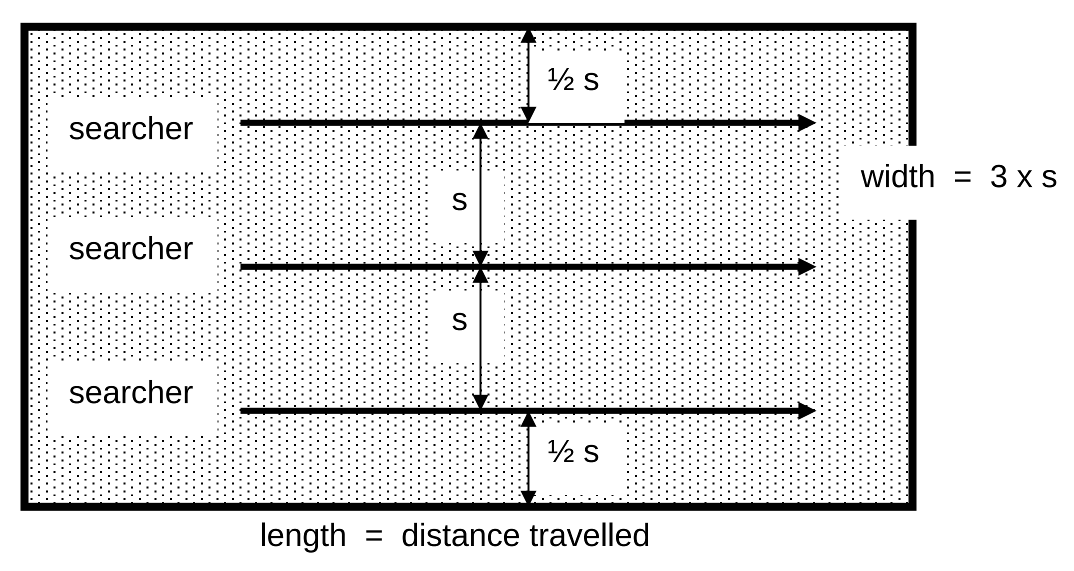

Figure 2: the corridor searched by a three person field team

Figure 2 shows the corridor searched in one sweep by a three person field team at a spacing of s. The area of this corridor (shaded) is the area to which the POD from the CS POD graph applies.

The procedure for finding CS

1. When the field team arrives at the start of the area that they are to search, they need to find a location that they consider to be representative of the area as a whole. They should take great care to make sure that, as far as possible, its terrain and vegetation are typical of the entire sector. This is where they will determine CS.
2. They put an object on the ground in the middle of their chosen location. They may give it an appropriately coloured covering so that it resembles the colour of the clothing worn by the missing person. A pack is a good body substitute for an adult; if they are searching for a specific size or type of clue, or a child, then they use something that is closer in size and appearance to that search object.
3. An even number of members of the field team gather round the object.
4. They then walk away from it, each heading in a direction that is directly opposed to their colleague on the other side of the object. They look back at the object at regular intervals. Each of them is trying to find the point at which they can no longer see it as they move away from it. The exact point at which this happens will need to be checked by moving towards and then away from the object. It would be useful if each searcher marked this point by putting a marker (for example a hiking pole or their pack) on the ground.
5. One member of the field team is selected as the pacer. It will be their job to measure the distance between the markers placed down by opposing pairs of searchers.
6. The pacer counts the paces between each opposing pair of markers.
7. They then find the average of these; this is CS for the field team in that location.
8. When the required spacing has been determined, the pacer paces out the spacing between searchers at the start of the area that they are to search.

If there are only three searchers in the team then it is recommended that after step 6 the two searchers who took part repeat steps 3 to 6, having each moved a quarter of a turn round the object; therefore if they originally walked in the directions east and west they will now head north and south. This will give a second distance for the pacer to measure. CS will be the average of these two distances.

If the terrain, vegetation or conditions change during the search by an amount that the field team considers would affect CS then they find it again by repeating the procedure.

Worked examples

For convenience, these three examples all take place in the same location, so that CS is the same in each case; they also all involve the same five person field team.

Example 1: this example focuses on the procedure for determining CS.

On day 2 of the search for a missing child, the field team is tasked to search a corridor along a path through some woods near to where the child was last seen. The path itself was searched as part of the initial response; this team's brief is to search along it at CS, with the middle searcher on the path and with two searchers in the woods on either side.

They arrive at the start of the section that they are to search, and find a suitable place in the woods adjacent to the path to find CS. One of the team has a small blue pack (the child was wearing a blue top), and they use that as the object. They place it on the ground and four of the team stand next to it, and then walk away in directions that just happen to be north, south, east and west. Each of them stops and marks their position with a hiking pole at the point where they lose sight of the pack, having checked it carefully by moving towards and away from the pack a few times. The fifth member of the team acts as pacer, and paces out the distance from the hiking pole positioned by the searcher who went north to that positioned by the searcher who went south, and counts 23 paces. The pacer repeats the process for searchers E and W, and counts 19 paces. CS is therefore taken to be 21 of the pacer's paces.

They then take up formation, with the searchers 21 of the pacer's paces apart, and with the middle searcher on the path. Since they are at CS then k = 1, and the CS POD graph shows that their POD for the corridor along the path is 50%.

Example 2: this example focuses on determining the spacing needed to achieve a particular POD.

Suppose that the IC wants the corridor along the path through the woods searched to give a POD of 75%; what spacing does this need?

The CS POD graph tells us that a POD of 75% requires k to be about 0.6 (more precisely k = 0.62). Since CS was found to be 21 of the pacer's paces, the spacing needed to give a POD of 75% is 0.6 x 21 or 13 paces.

The field team therefore space themselves out so that the searcher in the centre is on the path, and the searchers on either side are spaced at 13 of the pacer's paces. Note that this will result in a narrower corridor than the previous example.

Example 3: this example focuses on determining the POD for a field team whose spacing is determine by the width of the sector that they are about to search.

Suppose that the same five person field team is tasked to search an area between the path and a stream. If they search it in one sweep, what will the POD be? What would it be if they searched it in two parallel, adjacent sweeps?

The pacer paces out the distance between the path and the stream, and finds that it measures 150 paces. Therefore if the searchers were to line up across the sector such that they were equally spaced and with a half-spacing at either end, their spacing will be 150 / 5 paces (there will be 30 paces between the searchers and 15 paces at either end). But CS is 21 paces, and so k, which is calculated as spacing / CS, is 30 / 21, which is 1.4. The CS POD graph shows that a spacing of 1.4 x CS gives a POD of around 35%.

The IC says that this is too low, and suggests that they search the sector in two adjacent sweeps. This would halve the spacing, giving k = 15 / 21, which is 0.7 and gives a POD from the graph of just over 68%. The IC says that this is acceptable.

Conclusions

The method described in this paper has a number of advantages:

- it all happens at the time and place where the search is occurring, and does not rely on values from field trials conducted elsewhere
- it is based on critical separation, which is familiar to a large proportion of the land SAR community
- it gives a value of 50% POD for searching at CS; this is a well-known property of CS
- it does not involve any measuring equipment
- it gives a sufficiently accurate result if done carefully
- it gives members of the land SAR community access to the advantages of using search theory in terms of a consistent, reliable and robust procedure for the determination of POD

References

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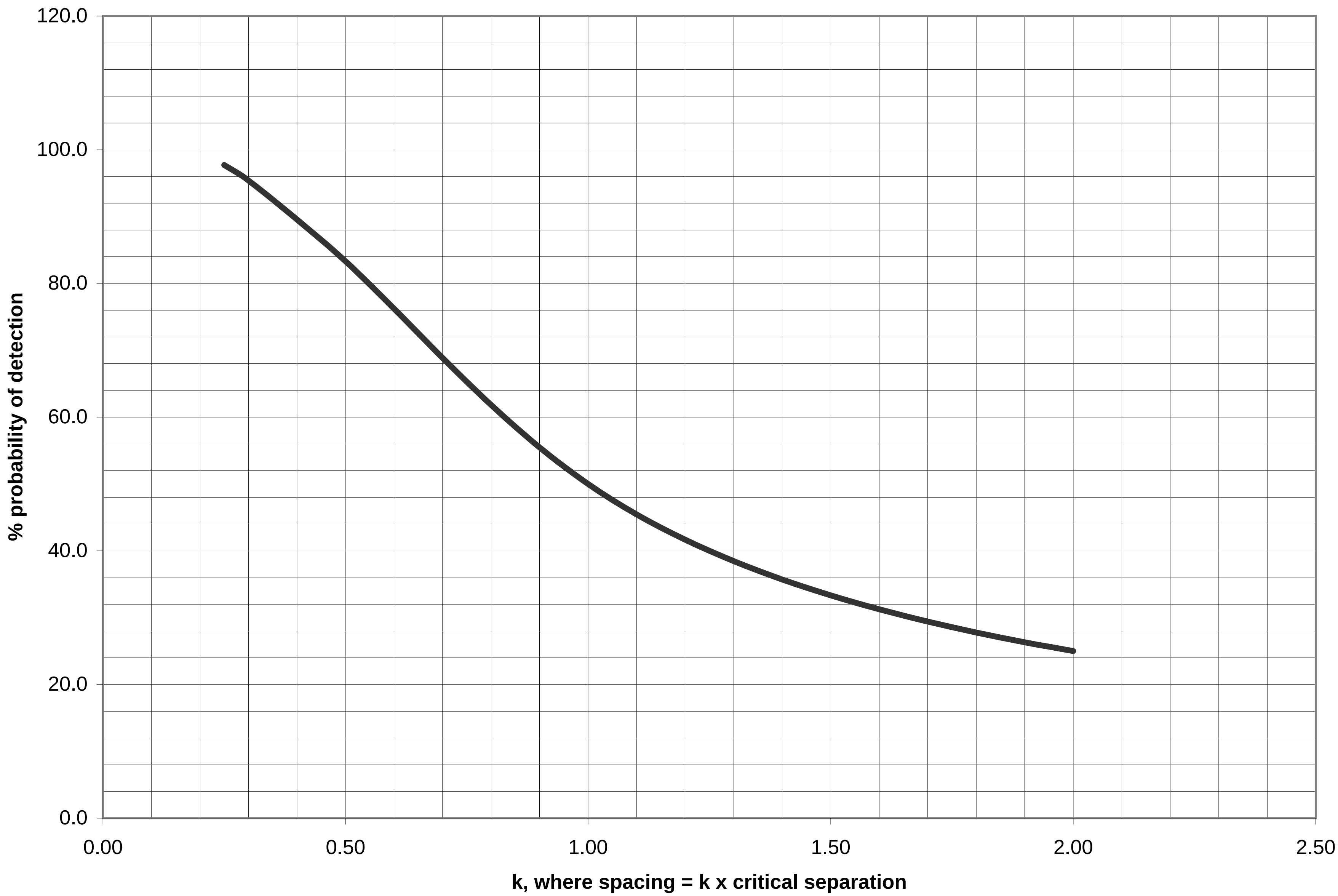
120.0
100.0
80.0
60.0
40.0
20.0
0.0
% probability of detection
0.00
0.50
1.00
1.50
2.00
2.50
k, where spacing = k x critical separation

k	C	pod %
0.25	2.00	97.7
0.3	1.67	95.4
0.4	1.25	89.6
0.5	1.00	83.3
0.6	0.83	76.2
0.7	0.71	68.9
0.8	0.63	61.8
0.9	0.56	55.5
1.0	0.50	50.0
1.1	0.45	45.5
1.2	0.42	41.7
1.3	0.38	38.5
1.4	0.36	35.7
1.5	0.33	33.3
1.6	0.31	31.3
1.7	0.29	29.4
1.8	0.28	27.8
1.9	0.26	26.3
2.0	0.25	25.0