Determining the search strip width based on range measurements

Jürg Schweizer
SLF Davos, Switzerland

1 Introduction

In the following the methods are shortly described that were used to determine the search strip width based on experimental range measurements. This summary is supposed to serve as a starting point for the discussion initiated by ICAR in the fall 2006 on how to find a common procedure to determine the search strip width.

We will in the following, as a first step, only consider one antenna transceivers. Subsequently, we will assess the differences for multiple antenna devices.

Before, it seems essential to recall some of the principals about avalanche rescue and the electromagnetic field of avalanche transceivers with a frequency of 457 kHz.

2 Background

2.1 Optimal search

When searching for an avalanche victim the primary issue is time. The faster you find the buried victim the higher is his or her chance of survival – on average.

How fast you can search with a transceiver depends on the range, or more precisely the search strip width (which is the lateral distance between individual rescuers) determines the area of avalanche debris you can cover in a given time – given a certain search velocity. If you increase the search strip width, the chances increase that you will not detect (or miss) the buried victim when searching the debris area the first time, but if you do find the victim it will be sooner than when using a narrow search strip width. In other words, the point is to optimize the chance of survival by finding an optimal search strip width (given a certain search speed).

If your search strip width is narrow the probability that you find the victim is very, very high, but it will take much longer, than if you apply a wider search strip width. Even if you miss the buried victim the first time, it is usually more effective to search again with the same width (because this is faster) than converting to a more narrow width[1]. These procedures and principals are well known from probing. Good (1972) proposed the two following extreme cases:

a) Probability of detection = 1 : time $\rightarrow \infty$: Chance of survival = 0
b) Chance of survival $\rightarrow$ 1 : time $\rightarrow$ 0 : Probability of detection = 0

The optimal probability of detection to maximize the probability of rescue is given by the search strip width and the search speed. The search strip width depends on the range, but as important on the target detection probability. A higher detection probability means a more narrow search strip width.

The detection probability is linked to the probability of survival. As an avalanche victim needs to be found within the first 15-20 minutes after burial (Brugger et al., 2001), and as shovelling easily takes up 5-10 minutes, the victim needs to be found within 10 minutes of burial. The probability of detection increases with time from the start of the search; simultaneously the probability of survival decreases. Accordingly, for a given time there is an optimal probability of detection so that the rescue probability (the probability to find the victim alive) is maximal (though decreasing with time). In the first 10 minutes of a search this optimal probability of detection is about 98% (Good, 1972; 1995).

If the probability of detection is set to 0.98, this means that in 98% of the cases a victim is detected whatever the relative antenna orientation between transmitting and receiving beacon. The probability of not detecting a buried victim between two search lines that are one search strip width apart, is then 0.0004.

Summing up, there are four important conclusions:

1. The search strip width needs to be chosen to maximize the chances of survival. Some thoroughness needs to be sacrificed in order to decrease search time.

2. Therefore, a probability of detection needs to fixed (how thorough you want to search). General agreement on this is required. In the past 0.98 was used. There is no need to change this.

3. The search strip width is then twice the range that guarantees this (chosen) probability of detection (e.g., the “98%”-range).

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[1] For example, when probing an avalanche area of 1000 m^2, the rescue probability with coarse probing (20 persons probing) is about 60%, whereas it is only about 20% for fine probing. It is assumed that the probability of detection is about 80% with coarse probing, and about 95% with fine probing (Good, 1972).

4. Consequently, there is no need to determine the minimal range (which tends to be zero and in consequence the chance of survival tends to be zero as well).

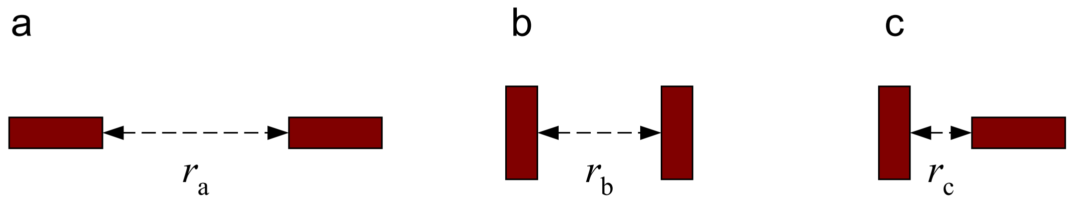

Figure 1: Antenna configurations: a) co-axial, b) parallel and c) perpendicular

2.2 Antenna configurations

The electro-magnetic field of a transmitting beacon at 457 kHz resembles a dipole in the near field (less than about 100 m). Again considering just one, the main and longest antenna also for receiving, there are three typical antenna configurations between transmitting and receiving beacon: a) co-axial, b) parallel and c) perpendicular (see Figure 1) (Meier, 2001).

The range in the three positions decreases from a) to b) to c). The range is maximal in co-axial position and minimal in perpendicular position. In some of the tests in the past (e.g., Krüsi et al., 1998; Semmel and Stopper, 2007) two perpendicular positions were tested. However, from a theoretical point of view – when considering one receiving antenna only – these two position are clearly identical.

Due to the properties of the electromagnetic field, it can be shown (Meier, 2001) that the range in parallel position r_b is about 80% of the range in coaxial position r_a:

$$r_b = \sqrt[3]{1/2}\, r_a . \qquad (1)$$

In configuration c) (perpendicular) the voltage induced in the antenna coil by the transmitting beacon is theoretically zero, i.e. the minimal range is by definition 0 m. In practise, even with only antenna receiving, a few meters will always be measured due to 1) slight deviations from the exact perpendicular orientation and 2) spurious emissions by parts of the transmitter circuits other than the antenna itself. For theoretical reasons as well as for practical ones (see above), it hence does not make sense to determine the range of a transceiver in the perpendicular position.

2.3 Statistics

When determining experimentally the range of a transceiver, for example, assuming a random antenna configuration between transmitting and receiving beacons, the range will vary. A variety of distances will be found. If plotted such that the frequency in a given range interval is counted, a more or less bell shaped curve is found (Figure 2).

The bell shaped curve which is the envelope of the data, can be described by the arithmetic mean m of all range measurements and its standard deviation σ (which is a measure of dispersion). Generally speaking, this description is acceptable if the data are symmetrical. Typically curves from range measurements are slightly truncated (on the left, towards zero).

If we assume the data to be normally distributed[2] (which is usually justified if the curve is close to a symmetrical bell shaped curve) then the mean minus two times the standard deviation denotes the lowest 2% of the data.

This means that given the characteristics of a normal distribution, the "98%"-range of a transceiver can be determined experimentally from the mean and the standard deviation of the test results. The "98%"-range has also been called useful range. The search strip width is than calculated to be twice the "98%"-range (see below).

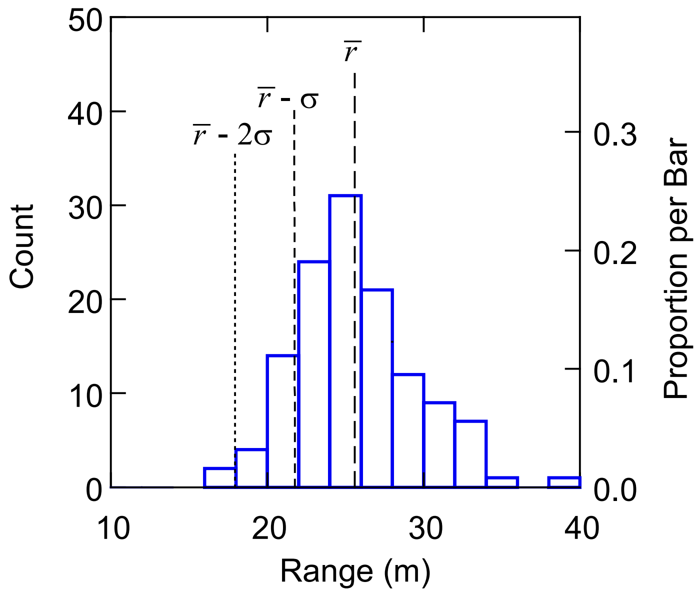

Figure 2: Typical results of range measurements: frequency distribution. In the above example, the mean $\bar{r}$ is 25.6 m, the standard deviation σ is 3.8 m.

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[2] Since test persons want to achieve good results the curves are often slightly truncated. This can be compensated by mirroring the values of the frequency distribution above the mean around the mean (Good, 1995).

3 Measuring and analysis methods

3.1 Method 1

If a large number of range measurements has been made with random antenna orientation (also called effective or usable range) the “98%”-range r_{98} can either be found by sorting the data and counting, i.e. determining the 2% percentile, or by assuming the data to be normally distributed and calculating the mean $\overline{r}$ and the standard deviation σ:

$$r_{98} = \overline{r} - 2\sigma . \qquad (2)$$

The search strip width is then defined as twice the “98%”-range:

$$w_1 = 2\, r_{98} . \qquad (3)$$

This is called Method 1. It is straightforward and represents the state of the art. However, it is not easy to properly design the experiment, and the experiment is time consuming, since a large number of tests is required. Also, the outcome depends to a large extent on the ability of the testing persons to try all relative antenna orientation with equal probability. A large dispersion among results from different tests is thus to be expected.

3.1.1 Experimental setup

In some of the earliest tests in 1964 and 1968, the transmitting beacons were buried left and right of a search line at various depths below the snow surface and with random antenna orientation. The searcher walks along the search line and moves the receiving device in order to reach the best possible coupling between the antenna. The best coupling (in practice) is usually achieved when the antenna of the two beacons are aligned in parallel position, as indicated by a maximal signal. The location where the searcher gets the first signal is recorded and the distance to the transmitting unit is calculated.

This experimental design got obviously forgotten, but was described again by Good (1995) and subsequently used again in the IKAR test of 1998 which was co-ordinated by Georges Krüsi, Frank Tschirky and Peter Weilenmann (Krüsi et al., 1998; Schweizer, 2000).

This experimental design is considered to be closest to actual conditions in a rescue situation, since the searcher passes the transmitting beacon with a random antenna orientation. It is well suited to determine the “98%”-range and to thereof calculate the search strip width as given above (Eq. 2).

Alternatively, in the ICAR test of 1998, the range was determined by approaching with three different antenna orientations (co-axial and two types of perpendicular, called in plane and vertical). This procedure resulted in rather wide distributions that sometimes even had two peaks.

3.2 Method 2

Based on experimental results in the 1960ties and 1970ties with the first generation of transceivers (Good, 1987) it was found that that the standard deviation was typically about ⅓ of the mean (for example, mean range: 15 m, standard deviation: 5 m). The maximum range (also called “2%”-range: r_{02}) is – in analogy to the “98%”-range – about equal to the mean plus two times the standard deviation. As the “2%”-range (or maximum range) can more easily be determined, the “98%”-range is calculated from the “2%”-range: it is just about 20% of the “2%”-range. Accordingly, the search strip width is about 40% of the “2%”-range which was determined in coaxial antenna orientation:

$$w_2 = 0.4\, r_{02} \quad . \tag{4}$$

This is Method 2, also called the 40%-rule. As mentioned above the method is based on the assumption that the standard deviation is about one third of the mean. Typically today, the standard deviation is much smaller (about 10-15% of the mean) so that applying the 40% rule leads to unnecessary low values of the search strip width (Schweizer and Krüsi, 2003).

3.3 Method 3

This is the method that was proposed by Felix Meier (Meier, 2001). If measuring the maximum range $r_{\max}$ of two co-axially aligned beacons, Meier (2001) proposed to calculate the width of the search strip w_3 from the measurements statistics as

$$w_3 = \bar{r}_{\max} - 2\sigma_{\max} \tag{5}$$

where $\bar{r}_{\max}$ is the average maximal range and $\sigma_{\max}$ is the standard deviation. This means that the width of search strip is just equal to the so-called “98%”-maximum range. This method requires that in an actual rescue situation the searching person actively rotates the beacon during the signal search (or primary search). The method takes into account adjustments for reduced performance due to factors such as a non-optimally aligned search beacon, low battery power or temperature effects.

The proposal by Meier (2001) seemed to be rather bold. However, the method was verified and found to even provide fairly conservative estimates compared to Method 1 (Schweizer and Krüsi, 2003).

Method 3 was developed by Meier (2001) to have an easy and fast testing method to determine the width of a search strip. In the following the basic assumption are shortly repeated, for details see Meier (2001).

The measurements are performed in the co-axial antenna orientation which gives reliable and reproducible results with an expected coefficient of variation (standard deviation divided by mean) of about 10%. From the measurements the "98%"-maximum range is determined. Then, three types of adjustments are made:

(1) It is assumed that the parallel antenna orientation can always be reached. As stated above, this reduces the range to about 80%.

(2) It is assumed that the searching person will not achieve the perfectly parallel position since the wrist cannot easily by rotated in three perpendicular directions by ±90°. Allowing the searching person to deviate by ±60° from the parallel orientation reduces the signal by another 50% which again results in another reduction in range to about 80%.

(3) Variations due to parameters such as transmitter battery voltage, transceiver and receiver temperature etc. are assumed to reduce the signal by another 50% which again results in a reduction of range to about 80%.

Combining these three reduction factors (or adjustments) gives a total reduction of ($0.8 \times 0.8 \times 0.8$) = 0.5, i.e. 50% [3]. 50% of the "98%"-maximum range is assumed to be the usable range. Twice the usable range is the search strip width. Hence, the search strip width is equivalent to the "98"-maximum range (Eq. 5).

[3] More precisely: $\sqrt[3]{1/2} \times \sqrt[3]{1/2} \times \sqrt[3]{1/2} = 1/2$

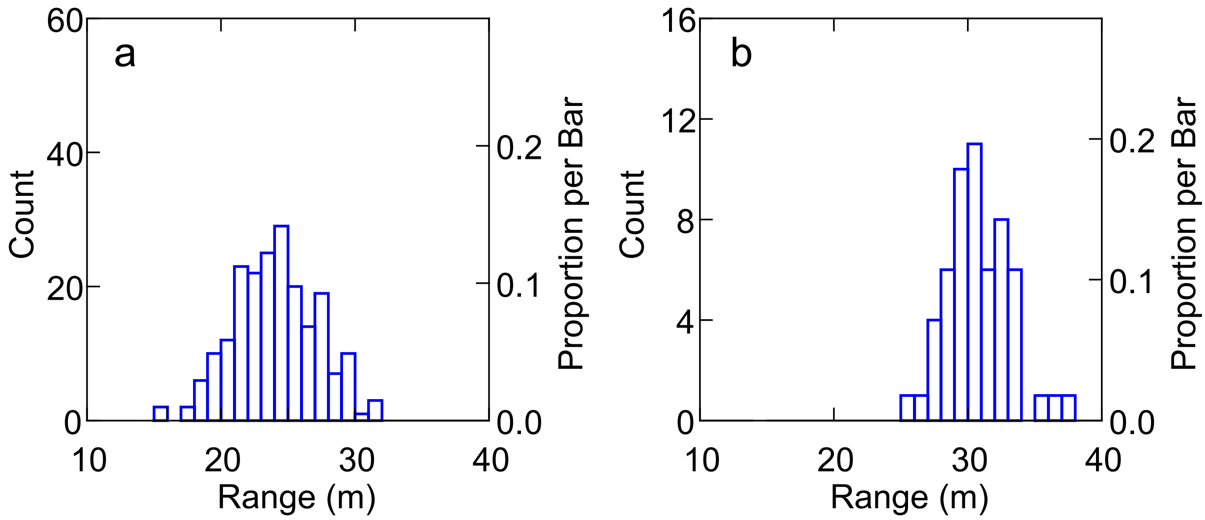

Figure 3: Results of range measurements: (a) Range measured by passing by a buried beacon with random antenna orientation (mean: 24.3 m, standard deviation 3.1 m). (b) Maximal range measured in co-axial antenna orientation (mean: 30.8 m, standard deviation 2.5 m).

As mentioned above the proposal was verified. Figure 3 shows an example from the tests described by Schweizer and Krüsi (2003). As can be seen in Figure 3, the range determined by passing by was about 80% of the maximal range as postulated by Meier (2001). In the example shown in Figure 3, the search strip width determined by Method 1 is about 36 m, whereas it is only 26 m when determined with Method 3. This clearly shows that Method 3 that initially seemed to be a fairly bold proposal, reveals in fact quite conservative values for the search strip width.

Schweizer and Krüsi (2003) have shown that by using different brands as transmitting beacons, the performance decreases by 10-20%, i.e. maximum range also depends on the properties of the transmitting beacon. This is not explicitly considered in Method 3 as proposed by Meier (2001).

Considering again the above example (Figure 3), if we assume that the medium range is reduced by 20% from 24.3 m to 19.4 m and the standard deviation stays the same (which in fact represents increased dispersion), the search strip width is reduced to 26.5 m. This value is just about equivalent to the value of the search strip width determined by Method 3. Consequently, it seems justified to postulate that reduced performance when searching a beacon of a different brand is taken into account within the third adjustment of Method 3.

Finally, Meier (2001) proposed that the second adjustment (for imperfect user cooperation) can be adapted to multiple antenna beacons that require less user co-operation. Instead of a reduction factor of about 0.8 for a one antenna beacon, the reduction factors is 0.9 for two antenna beacons provided that both antennas have equal sensitivity. There is a single beacon on the market today that meets this criterion. No correction factor needs to be applied for transceivers with three receiving antennas, again provided that all three of them have equal sensitivity. None of the beacons on the market today meets this criterion, and no one probably ever will, since this would imply a beacon about the size of a football. Accordingly, the search strip width for beacons with one, two or three antennas (A) would be:

$$w_3(A=1) = 1.0\,(\bar{r}_{\max} - 2\sigma_{\max}) \tag{6}$$

$$w_3(A=2) = 1.13\,(\bar{r}_{\max} - 2\sigma_{\max}) \tag{7}$$

$$w_3(A=3) = 1.26\,(\bar{r}_{\max} - 2\sigma_{\max}) \tag{8}$$

3.4 Method 4

Occasionally in the past, and again most recently (Semmel and Stopper, 2007), it was tried to determine the search strip width by measuring the minimal range. Consequently, twice the minimal range would then be the search strip width.

As shown above, this method does not make sense – for theoretical and practical reasons – and will not be further discussed.

4 Discussion

In 2001 the SLF performed a field test to determine range (Schweizer 2002; Schweizer and Krüsi, 2003). Methods 1, 2 and 3 were applied and compared. Whereas Method 1 can be considered the state of the art, it is fairly time consuming and a large number of tests is required. On the other hand, Method 3 requires a smaller test sample than Method 1 and gives more repeatable values. Compared to Method 1, Method 3 revealed fairly conservative values of the search strip width. Method 2 is clearly outdated since the standard deviation is today less than one third of the mean. Method 4 was not considered but for fundamental reasons does not make sense. Other reliable methods do not exist to my knowledge.

If applying a search strip width determined with Method 3, the searcher has to rotate the receiving beacon (at least with one antenna beacons) during the initial search for a signal. However, this has been instructed for many years and is standard practice (e.g. "…orienting the unit for optimal antenna direction.") (e.g., Daffern, 1992; Gabl and Lackinger, 1996; Wassermann and Wicky, 2003).

It seems important to recall that the search strip width is an essential factor in the race against the strongly decreasing survival chances of an avalanche victim.

Therefore, when experimentally determining the search strip width based on range measurements, the resulting value, for example 28 m, should in any case be rounded up to 30 m (or even 100 ft). The searcher should not be afraid of using a too large search strip width since this usually increases the chance of survival for a victim rather than decreasing it. This is analogous to coarse vs. fine probing.

5 Conclusions and recommendation

Based on the above considerations, the method proposed by Meier (2001) is the one best suited to determine the search strip width. The search strip width should be determined experimentally by measuring the maximum range in co-axial antenna orientation. Three beacons of the same brand should alternatively be used as transmitters and receivers (resulting in six different setups). At least six measurements should be performed with each setup giving a total of 36 range measurements. Calculating the mean and standard deviation of 36 measurements should give a result with sufficient accuracy. According to the number of receiving antennas Eq. 5-7 can be used to determine the search strip width.

6 Outlook – Future developments

Some of the assumptions above are fairly conservative and the approach is to a certain level a worst case approach. With today's computer power, it is possible to run a large number of scenarios based on, for example, avalanche statistics. With the help of this type of simulations the search strip width can be optimized such that the survival chance is maximal[4]. Good (1972) had already considered in the 1970ties a number of scenarios and concluded that for a small avalanche the survival chance was optimal for a probability of detection of 98%. For larger avalanches he found that a lower probability of detection – and hence a larger search strip width – would be optimal.

In the future, simulations may be used to consider not only average or worst case scenarios but a realistic variety of scenarios. However, agreement will need to be achieved on realistic distributions of, for example, the size of the avalanche deposit. The approach is outlined in Figure 4. Some preliminary results – just to illustrate the approach – are given in Figure 5.

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[4] This approach has been proposed by Manuel Genswein in September 2007.

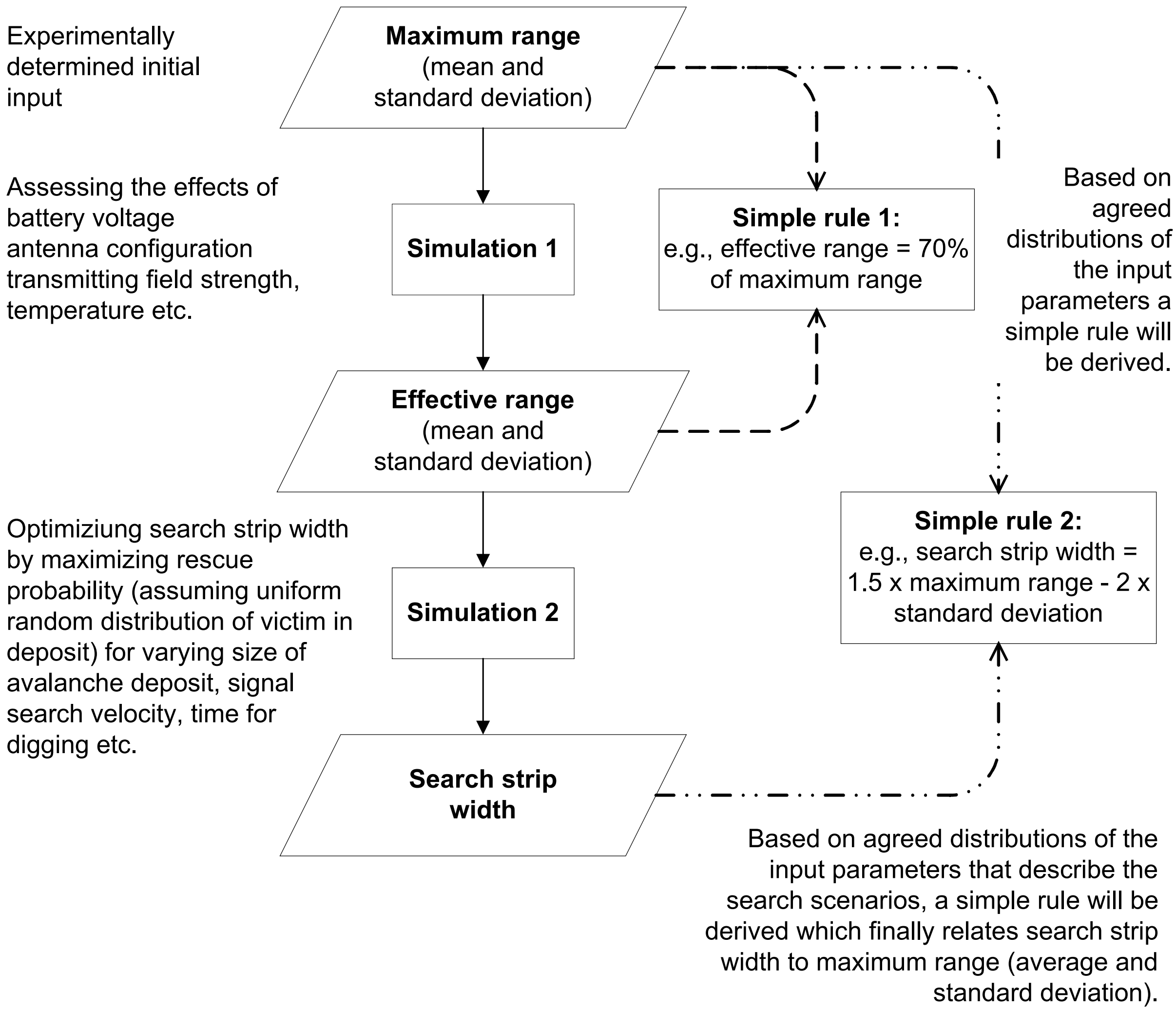

Figure 4: Schematic outline of simulation approach

For the simulations in Figure 5 an effective range (Method 1 above) of 30 m ± 5 m was assumed. Other assumptions included 1 m/s for the speed of signal search, 0.5 m/s for the secondary search and 10 Min for digging-out the victim. The survival probability curve from Falk et al. (1994) as updated on the avalanche emergency web page was used. The number of realizations was 100’000.

Figure 5a shows a typical result for an avalanche deposit size of 10’000 m^2. In addition, the standard deviation is varied. The rescue probability is maximal for a search strip width of about 48 m. The maximum of the rescue probability results from the fact the number of misses, i.e. the victims not found when first searching the deposit increases with increasing search strip width whereas the proportion of the victims that are found dead decreases with increasing search strip width. In other words, a small search strip width means that all victims are found, but due to the longer time that is used to find the victim the chance that the victim can only be found dead increases. On the other hand, if the search strip width is large, some of the victims might not be found initially but those found are more likely still alive.

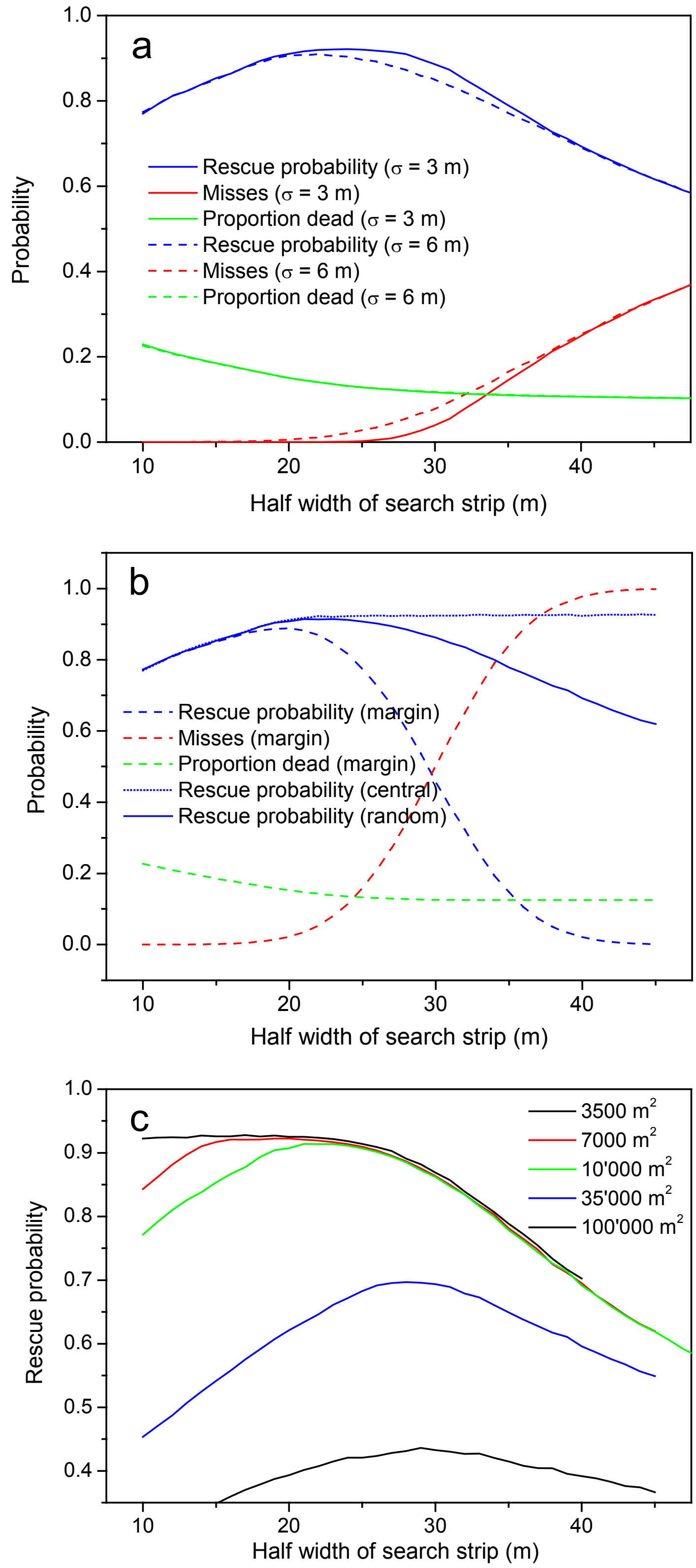

Figure 5: Preliminary simulation results. (a) Rescue probability, proportion of misses and proportion of victims that were found dead for two different standard deviations of the effective range. (b) Effect of location of victim on rescue probability. (c) Effect of avalanche deposit size. See text for simulation assumptions.

Obviously, a larger standard deviation (i.e. more dispersion in effective range) means a lower search strip width. The effect is relatively minor.

Figure 5b shows the effect of the location where the victims are in relation to the search strip central line. The following cases are considered: (a) all victims are at the margin of the search strip (worst case), (b) all victims are buried along the center line, and (c) the victims are randomly distributed within the area covered by the search strip (uniform random distribution).

Figure 5c shows the effect of avalanche size. For very large deposits a large search strip width is most promising. For small up to medium sized deposits the question of search strip width is virtually irrelevant at least for the effective range considered (30 m).

The above results are meant to just give an idea on what can be done with simulations. This procedure will produce search strip widths that are even larger (probably up to about 50%) than what is recommended above. I believe that this desirable as it increases the survival chance. However, for the time being, I suggest to proceed with the above recommendation which already represents a substantial step towards an optimized search strip width.

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